handbook of power

RESISTORS

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HANDBOOK OF POWER RESISTORS

Compiled by

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WARD LEONARD ELECTRIC CO.

THIRD EDITION

WARD LEONARD ELECTRIC CO.
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HANDBOOK OF POWER RESISTORS

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FOREWORD

Although the history of resistor manufacture dates back to the discovery of electricity, detailed information on power resistor construction and characteristics still remains the property of a few specialists. The literature of the electrical industry has treated other control components in copious detail. Power resistors, perhaps the most common of all, have probably for this very reason suffered from neglect.

This handbook represents an effort to present a more comprehensive analysis of the construction of power resistors, and their application and performance characteristics. The material herein presented stems from more than half a century of practical design and manufacturing experience by the Ward Leonard Electric Co. and represents the collective effort of its sales and engineering staffs. Because the applications of power resistors are so broad in scope, an extended analysis of specific application problems has not been attempted in this edition.

It is our hope that this handbook will aid in promoting a broader understanding of power resistor construction and characteristics and serve as a helpful guide to the student, application engineer, and equipment manufacturer interested in the subject.

A. A. BERARD
President
Ward Leonard Electric Co.

CONTENTS

PAGE

CHAPTER III. TYPES OF RESISTORS

Table of Contents

CHAPTER I

General Resistor Considerations

A. BASIC DEFINITIONS.

The following definitions of fundamental resistor terms are presented for the purpose of establishing a basis of discussion and understanding. The recurrent use of these terms without a clear and concise appreciation of their significance would lead to misconceptions. For a more complete list of definitions and functions refer to Chapter VIII, DEFINITIONS.

1. *Resistance*—Resistance is the (scalar) property of an electric circuit or of any body that may be used as part of an electric circuit which determines for a given current the rate at which electrical energy is converted into heat or radiant energy and which has a value such that the product of the resistance and the square of the current gives the rate of conversion of energy.

In the general case, resistance is a function of the current, but the term is most commonly used in connection with circuits when the resistance is independent of the current.*

2. *Resistor*—A resistor is a device, the primary purpose of which is to introduce resistance into an electric circuit.*

3. *Conductor*—A conductor is a body so constructed from conducting material that it may be used as a carrier of electric current.*

4. *Resistive Conductor*—A resistive conductor is a conductor used primarily because it possesses the property of high electric resistance.*

5. *Hot Spot*—The hot spot is the point or location of maximum measurable temperature on the surface of a device.

*ASA Standard

6. *Ambient Temperature*—Ambient temperature is the temperature of the surrounding cooling medium, such as gas or liquid, which comes into contact with the heated parts of the apparatus.*

7. *Test Conditions*—Two optimum, or laboratory, conditions are generally understood to be true when ratings of resistors are discussed, namely, free space and still air.

a. Free space. Free space is that condition wherein no physical object is within one foot of any part of the resistor, or resistor assembly, under consideration.

b. Still air. Still air is considered to be air having no circulation other than that due to convection currents created by the heat of the resistor being operated.

c. The expression "Free Air" is used throughout the text to denote both conditions of free space and still air.

d. Throughout this book, ambient temperature shall be considered 40°C unless otherwise specified.

B. PERFORMANCE STANDARDS.

The electrical energy dissipated by a resistor is converted into heat energy. The ultimate temperature rise of intermittent-duty resistors is governed largely by the watt input, the time cycle, and by the mass and specific heat of the entire assembly. The larger the watt input and the shorter the time-on period, the more important are the mass and specific heat of the material. With continuous-duty resistors the ultimate temperature rise is obtained when stability is reached between the heat radiated, plus that carried off by conduction and convection, and the heat generated by the I^2R loss.

1. *Temperature Test—Resistors*

a. When a temperature test is made on an intermittent duty resistor, the resistor should be connected to a voltage that would give the root mean square

*ASA Standard

current of the cycle continuously for the "time on" period specified. The specified cycles of "time on" and "time off" shall be repeated for one hour.

For temperature tests on intermittent duty resistors for D.C. and A.C. motor starting purposes, refer to NEMA Standards IC1-4.3 and IC1-4.5, Pages 150 and 151 respectively.

b. When a temperature test is made on a continuous-duty resistor without its motor, any tested step shall be subjected to 100 percent of the current for which it is designed, and this value of current shall be maintained until the maximum temperatures are reached.**

c. When a temperature test is made on a rheostatic dimmer, it shall be made on a single plate which is operated at rated voltage and connected in series with lamps totalling the rated lamp load.**

2. *Temperature of Resistors*

a. When a temperature test is made on a resistor, rheostat or dimmer at the current values, duty cycle and elapsed time specified, the limiting temperature rise above the cooling air and the methods of temperature measurement shall be as follows:

(1) For bare resistive conductors, the temperature rise shall not exceed 375°C as measured by a thermocouple in contact with the resistive conductor.

(2) For resistor units, rheostats and wall-mounted rheostatic dimmers which have an embedded resistive conductor, the temperature rise shall not exceed 300°C as measured by a thermocouple in contact with the surface of the embedding material.

(3) For rheostatic dimmers which have embedded resistive conductors and which are arranged for mounting on switchboards or in non-combustible frames, the temperature rise shall not exceed 350°C as measured by a thermocouple in contact with the surface of the embedding material.

(4) The temperature rise of the issuing air shall

**NEMA Standard

not exceed 175°C as measured by a mercury thermometer at a distance of 1 inch from the enclosure.**

C. WIRE OR RIBBON POWER TYPE RESISTORS.

A non-functional breakdown of basic power resistor types indicates the following four variations:

1. *Fixed Resistor*—A fixed resistor is one designed to introduce only one predetermined amount of resistance into an electrical circuit.

2. *Tapped Resistor*—A tapped resistor is one designed to introduce one of several predetermined amounts of resistance into an electrical circuit, dependent upon the number of resistor terminals employed.

3. *Adjustable Resistor*—An adjustable resistor is a resistor so constructed that its resistance can be readily changed over values within its range.

4. *Multi-section Resistor*—A multi-section resistor is a resistor having two or more electrically independent sections.

For complete analysis of resistor types and functional applications, refer to Chapter III, TYPES OF RESISTORS.

D. BASIC POWER RESISTOR FUNCTIONS.

Although every resistor basically performs the prime function of introducing resistance into an electrical circuit, and thereby converting electrical energy into heat energy, this may be done for several different practical reasons.

1. *Heating*—Resistors are often employed in order to use directly the heat energy generated. Electric stoves, toasters, irons, and numerous other devices make direct use of the heat energy generated by the flow of electrical current through a resistive conductor.

2. *Current Limiting*—It is often necessary to restrict the amount of current flow through a particular circuit or portion thereof. The introduction of a resistor into the circuit performs this function. For the proper value

**NEMA Standard

of resistance to be inserted, refer to Section E, FUNDAMENTAL RESISTANCE CALCULATIONS.

3. *Voltage Drop*—A "voltage dropping" resistor is one whose main purpose is to reduce the applied voltage for a particular application. The reduction in voltage is a function of the current through the resistor and the resistance value (E=IR).

4. *Voltage Divider*—A "voltage divider" resistor provides the voltages required for various circuits when each circuit is drawing a predetermined current through the divider.

5. *Discharge*—It is advisable to discharge the stored energy in certain circuits to prevent damage to electrical equipment from excess voltage surges. This is accomplished by discharging the stored energy through a resistor.

E. FUNDAMENTAL RESISTANCE CALCULATIONS.

The computation of resistance values is actually the determination of the relationship existing between electrical potential in volts, current in amperes, and the resistance value in ohms. Ohm's Law is the rule for determining the relationship.

1. *Ohm's Law*—This fundamental law of the electric circuit may be stated as follows: The current in a circuit is directly proportional to the circuit EMF (electromotive force) and inversely proportional to the circuit resistance.

Ohm's Law may be expressed in three ways as follows:

R equals E over I (E divided by I) $R = \frac{E}{I}$

I equals E over R (E divided by R) $I = \frac{E}{R}$

E equals I times R $E = I \times R$

where R is resistance in ohms, I is current in amperes, and E is electrical potential in volts.

Example 1: Knowing the voltage in a circuit to be 6 volts and the current to be 0.6 ampere, the resistance value is found as follows:

$$R = \frac{E}{I} = \frac{6}{0.6} = 10 \text{ ohms}$$

Example 2: Having a voltage supply of 6 volts to feed a vacuum tube filament that operates at 1.5 volts and draws 0.25 amperes, first subtract 1.5 from 6 to obtain the voltage drop across the dropping resistor which, in this case, is 4.5 volts. Then apply the formula as follows to find the resistance value necessary:

$$R = \frac{E}{I} = \frac{4.5}{0.25} = 18 \text{ ohms}$$

Example 3: It is desired to determine the voltage drop across a 20 ohm resistor in which the current is 0.25 amperes. The voltage drop is found as follows:

$$E = I \times R = 0.25 \times 20 = 5 \text{ volts}$$

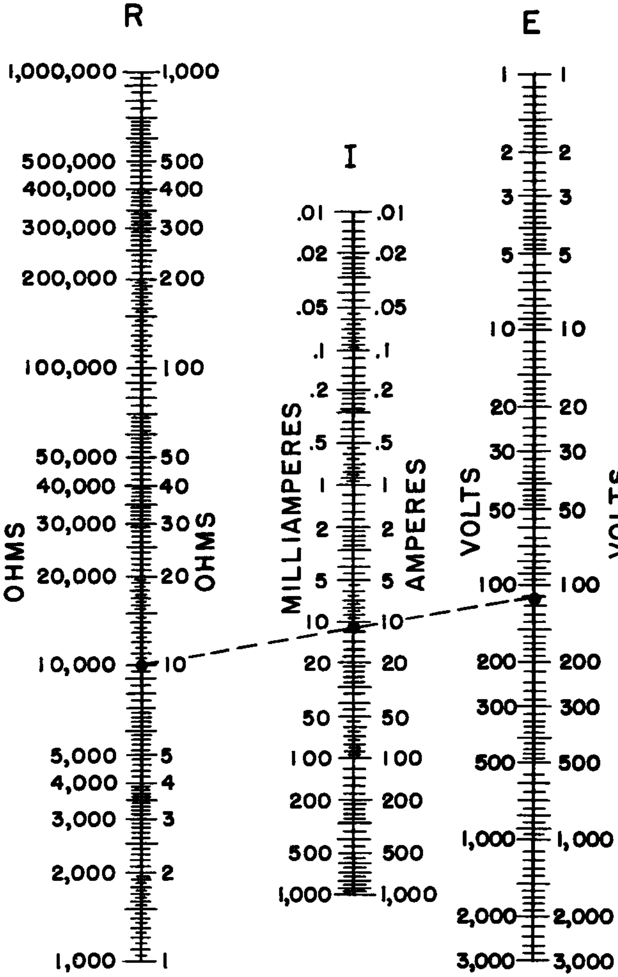
2. *Ohm's Law Nomograph*—The Ohm's Law nomograph, Figure 1-1, provides a ready graphical solution to Ohm's Law problems, as illustrated by the following example:

To find the current flowing through a 10 ohm resistor connected across a 115 volt supply draw a line from 10 on the R scale to 115 on the E scale and read the answer where the line crosses the I scale, i.e., 11.5 amperes.

Similarly, the resistance may be determined, given the voltage and current, and the voltage may be obtained knowing the current and resistance.

3. *Resistors in Series*—When resistors are connected in series, the total resistance is obtained by adding all values together. Thus, if a 5 ohm, a 10 ohm, and a 15 ohm resistor are connected in series, the total value is $5 + 10 + 15 = 30$ ohms.

$$R_{TOTAL} = R_1 + R_2 + R_3 \ldots\ldots\ldots + R_n \text{ Ohms}$$



Use numbers on the left with numbers on the left only, and numbers on the right with numbers on the right only.

Figure 1-1. Ohm's Law Nomograph

The Ohm's law nomograph is equally applicable to resistors in series, using R_{TOTAL} in lieu of the single resistor given in the example.

4. *Resistors in Parallel*

For resistors in parallel:

$$\text{Total Resistance } R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \cdots\cdots \frac{1}{R_n}} \text{ Ohms}$$

For two resistors in parallel:

$$\text{Total resistance } R_T = \frac{R_1 \times R_2}{R_1 + R_2}$$

When the resistance of one resistor and the total resistance are known, the formula is conveniently written:

$$R_2 = \frac{R_T \times R_1}{R_1 - R_T}$$

When the resistance values are all equal, the total parallel resistance is equal to the resistance of one resistor divided by the number of resistors. For example, the total resistance of two equal resistors in parallel is one-half that of one, while the parallel resistance of three equal resistances is one-third that of one.

Example 1: Find the overall resistance when an 8 ohm, a 20 ohm, and a 40 ohm resistor are connected in parallel.

Applying the formula

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} = \frac{1}{\frac{1}{8} + \frac{1}{20} + \frac{1}{40}} = \frac{1}{\frac{8}{40}} = 5 \text{ ohms}$$

5. *Parallel Resistance Nomograph*—This graphical device, Figure 1-2, enables the total resistance of two or more resistors in parallel to be determined readily. The dotted lines indicate the solution of an example involving three resistors of 15, 10 and 5 ohms respectively.

Draw a line from 10 on scale A to 15 on scale B.

Where this line cuts scale E is the total resistance of 10 ohms and 15 ohms in parallel, or 6 ohms. Now draw a line from 6 on scale E to 5 on scale C. Where the second line cuts scale D is the total resistance of all three in parallel, or 2.73 ohms.

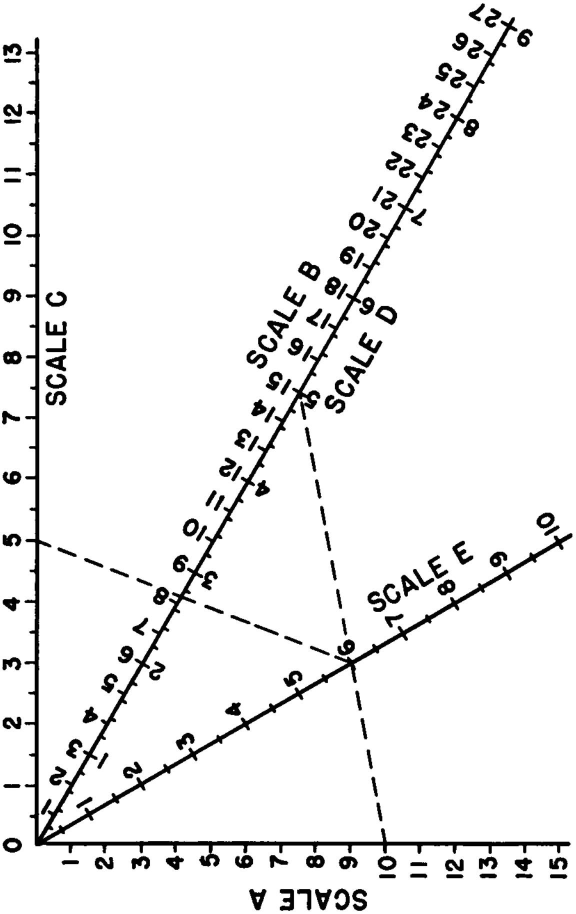


Figure 1-2. Parallel Resistance Nomograph

To add a fourth resistor in parallel, use 2.73 on scale A and the fourth resistor on scale B. More resistors may be added in a similar manner.

The units on the nomograph may be multiplied by any multiple of 10 in order to solve problems dealing with higher resistance values. If one scale is multiplied all the others must also be multiplied in the same manner.

6. *Kirchoff's Laws*—In the solution of circuit problems, two fundamental relationships known as Kirchoff's Laws may be used. These are:

Current: The algebraic sum of the currents flowing toward any junction point is zero.

Voltage: The algebraic sum of the voltages around any closed path in a network is zero.

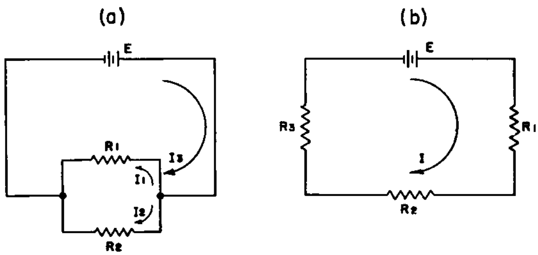


Figure 1-3. Illustration of Kirchoff's Laws

In Figure 1-3a, assume that $E=10$ volts, $R_1=2$ ohms, $R_2=5$ ohms. Then, using Kirchoff's Law for current:

$$I_3 = I_1 + I_2$$

From Ohm's Law:

$$I_1 = E/R_1 = 10/2 = 5 \text{ amperes}$$

$$I_2 = E/R_2 = 10/5 = 2 \text{ amperes}$$

Therefore, $I_3 = 5 + 2 = 7$ amperes

In Figure 1-3b, assume that $E = 10$ volts, $R_1 = 1$ ohm, $R_2 = 2$ ohms, $R_3 = 5$ ohms. Then using Kirchoff's Law for voltage and Ohm's Law:

$E = IR_1 + IR_2 + IR_3$ and $I = E/(R_1 + R_2 + R_3) = 10/8 = 1.25$ amperes.

Therefore, $E = 1.25 \times 1 + 1.25 \times 2 + 1.25 \times 5 = 10$ volts.

Or, 10 volts = 10 volts, the voltage rise through the voltage source being equal to the sum of the voltage drops around the closed circuit.

7. *Wye and Delta Resistance Combinations.*

In circuit calculations it is often convenient to make use of a mathematical device known as delta-wye (or wye-delta) conversion. For example, referring to Figure 1-4, a delta circuit consisting of resistors A, B and C, and having terminals 1, 2 and 3, may be replaced by an equivalent wye consisting of resistors a, b and c. The following equations apply:

Conversion from delta to wye:

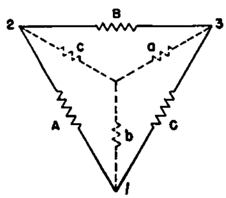


Figure 1-4

$$a = \frac{BC}{A + B + C}$$

$$b = \frac{AC}{A + B + C}$$

$$c = \frac{AB}{A + B + C}$$

Conversion from wye to delta:

$$A = \frac{ab + bc + ca}{a}$$

$$B = \frac{ab + bc + ca}{b}$$

$$C = \frac{ab + bc + ca}{c}$$

8. *Power Rating and Current Carrying Capacity*—Resistors are rated in watts, also in current carrying capacity, and as the resistance value of a resistor of a given watt rating is increased the current carrying capacity decreases. If the current flowing through a resistor of a given size and watt rating exceeds that as determined by the formulas presented below, the resistor will be overloaded and it will generate more heat than if operated at its rated current carrying capacity. Overloading tends to shorten the life of a resistor. Also, other apparatus in the circuit may be damaged by the excessive temperature rise of the resistor.

The basic formula for power is as follows:

W equals E times I $W = E \times I$

E equals W over I (W divided by I) $E = \frac{W}{I}$

I equals W over E (W divided by E) $I = \frac{W}{E}$

Where W is power in watts, E is electrical potential in volts, and I is current in amperes.

By substituting the values of E and I as determined by applying Ohm's Law, we obtain other formulas as follows:

W equals I squared times R $W = I^2 R$

I equals the square root of W over R $I = \sqrt{\frac{W}{R}}$

R equals W over I squared $R = \frac{W}{I^2}$

W equals E squared over R $W = \frac{E^2}{R}$

E equals the square root of R times W $E = \sqrt{R \times W}$

R equals E squared over W $R = \frac{E^2}{W}$

The following examples will show some applications of the formulas:

Example 1: Find the current carrying capacity of a 20 watt resistor of 5 ohms.

$$I = \sqrt{\frac{W}{R}} = \sqrt{\frac{20}{5}} = \sqrt{4} = 2 \text{ amperes}$$

Example 2: Find the required watt rating of a 20 ohm resistor to carry 1 ampere:

$$W = I^2 R = (1)^2 \times 20 = 1 \times 20 = 20 \text{ watts}$$

9. *Ohm's Law Table for Direct Current Circuits*—The following table conveniently summarizes the various forms of Ohm's Law previously explained. In using the formulas for the solution of problems make sure that a consistent system of units is employed. Reduce all terms to volts, amperes and watts. 5 K.W. must be expressed as 5000 watts, 70 milliamperes as 0.070 amperes, 5 megohms as 5,000,000 ohms.

Ohm's Law Equations for D.C. Circuits

W = Watts	EI	I^2R	$\frac{E^2}{R}$			
E = Volts		IR		$\sqrt{WR}$		$\frac{W}{I}$
I = Amperes			$\frac{E}{R}$	$\sqrt{\frac{W}{R}}$	$\frac{W}{E}$	
R = Ohms	$\frac{E}{I}$				$\frac{E^2}{W}$	$\frac{W}{I^2}$

10. *Ohm's Law Table for Alternating Current*—The previously explained equations refer to resistors in D.C. circuits. For A.C. circuits involving inductive or capacitive reactances in addition to resistance, the equations in the following table should be used.

Ohm's Law Equations for Single Phase A.C. Circuits

E Volts	IZ	$\frac{W}{I \cos\theta}$	$\frac{\sqrt{WR}}{\cos\theta}$	$\sqrt{\frac{WZ}{\cos\theta}}$		
I Amperes	$\frac{E}{Z}$	$\frac{W}{E \cos\theta}$	$\sqrt{\frac{W}{R}}$	$\sqrt{\frac{W}{Z \cos\theta}}$		
R Ohms	$\frac{E}{I} \cos\theta$	$\frac{(E \cos\theta)^2}{W}$		$Z \cos\theta$	$\frac{W}{I^2}$	$\sqrt{Z^2 - X^2}$
Cos θ Power Factor	$\frac{IR}{E}$	$\frac{W}{I^2 Z}$	$\frac{WZ}{E^2}$	$\frac{R}{Z}$	$\frac{W}{EI}$	$\frac{R}{\sqrt{R^2+X^2}}$
Z Ohms	$\frac{E}{I}$	$\frac{W}{I^2 \cos\theta}$	$\frac{R}{\cos\theta}$	$\frac{E^2 \cos\theta}{W}$		$\sqrt{R^2+X^2}$
X Ohms	$(X_L - X_C)$		$\left(2\pi fL - \frac{1}{2\pi fC}\right)$			$\sqrt{Z^2 - R^2}$
W Watts	$EI \cos\theta$	$\frac{E^2 \cos\theta}{Z}$	$I^2 Z \cos\theta$	$I^2 R$		

C = Capacitance
L = Inductance
X_C = Capacitive Reactance
X_L = Inductive Reactance
Z = Impedance
θ = Angle of lead or lag
f = Frequency

11. *Wire Resistance*—The resistance of a conductor is a function of its length, area and resistivity. The equation for the resistance of a wire of length l (in feet) and cross-sectional area A (in circular mils) is

$$R = \frac{\rho\, l}{A}$$

where ρ is the resistivity of the conductor expressed in ohms per circular-mil-foot. A circular mil is a unit of area given by $A = d^2$, where d is the diameter of the wire in mils (thousands of an inch). One square inch of wire therefore contains 1,273,240 circular mils. At a temperature of 20°C, ρ for copper is 10.37 ohms per circular-mil-foot.

The resistance of a conductor changes to some extent with temperature. The change may be calculated from the temperature coefficient of resistivity. With some metals and alloys the change in resistance with increase or decrease in temperature can be considered a straight-line function over the range of temperature usually encountered. With other alloys and metals the change in resistance with temperature change may be negative over a certain temperature range, and positive over a different temperature range.

The temperature coefficient of resistivity may be expressed as:

$$a = \frac{R_{t_2} - R_{t_1}}{R_{t_1}(t_2 - t_1)} \quad \text{or}$$

$$R_{t_2} = R_{t_1}[1 + a(t_2 - t_1)]$$

where R_{t_1} and R_{t_2} are the resistances in ohms at temperatures t_1 and t_2, degrees centigrade, respectively and a is the temperature coefficient of resistivity.

For copper, the temperature coefficient of resistivity is .00393, t_1 being taken as 20°C for convenience.

Thus, for a copper resistor, whose resistance at 20°C is 50 ohms, a 100°C rise in temperature would increase the resistance to:

$$R_2 = 50\,(1 + .00393 \times 100) = 50 \times 1.393 = 69.6 \text{ ohms}$$

The temperature coefficient of resistivity of a typical nickel chromium alloy (Ni-Cr:80-20) is 0.00013 at 20°C. A 50 ohm resistor of this material, subjected to the same temperature rise of 100°C would have its resistance increased to:

$$R_2 = 50\,(1 + .00013 \times 100) = 50 \times 1.013 = 50.6 \text{ ohms}$$

The above examples illustrate the wide variation in performance that can be obtained, depending on the materials used in the manufacture of a resistor.

CHAPTER II

Materials For Resistors

A. GENERAL CONSTRUCTION.

Power resistors generally are composed of one or more of the following parts:

1—A resistive conductor
2—A support for the resistive conductor
3—Terminals for connecting to the resistive conductor
4—A means of protecting the resistive conductor

These separate parts, in turn, are mechanically combined into a finished resistor.

B. RESISTIVE CONDUCTORS.

Resistive conductors for power resistors are made of alloys or metals in wire or ribbon form. Several of the more common forms of resistive conductors are illustrated in Figure 2-1. The particular form selected depends primarily on the requirements of the particular resistor application and secondarily on the individual manufacturer's experience with the various materials used in conjunction with his individual production processes.

In actual practice, when choosing a material for a resistive conductor, the resistor design engineer endeavors to obtain:

1—A material whose resistivity will allow for selection of good mechanical strength, permitting the proper wire diameter or ribbon thickness to ensure against microscopic flaws, hardspots, or breakage due to mechanical strain.
2—A material that has stable characteristics over the intended operating and manufacturing temperatures.
3—A material that is capable of being readily manufactured.
4—A wire or ribbon that is readily usable with the support, terminals and protective materials.
5—A resistive conductor that is economical from the standpoint of material cost.

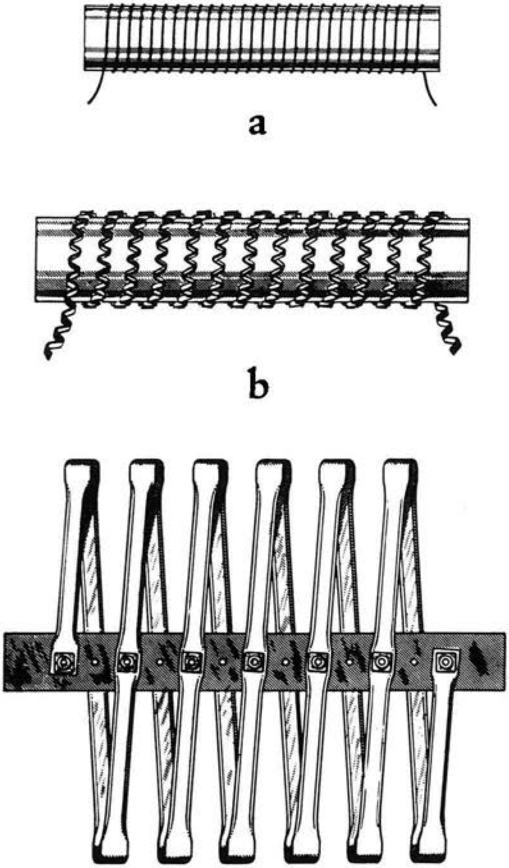


Figure 2-1a. Typical Forms of Wire or Ribbon Resistive Conductors.

a—Round wire—single layer, b—Reflexed ribbon—wound on edge, c—Channel shaped ribbon.

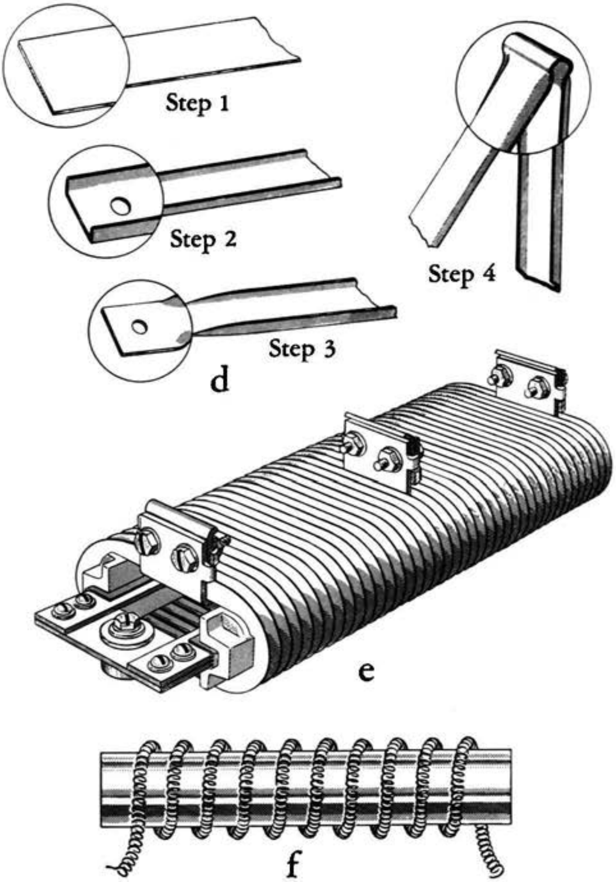


Figure 2-1b. Typical Forms of Wire or Ribbon Resistive Conductors

d—Steps in forming channeled ribbon from flat alloy resistance ribbon, e—Oval shaped ribbon coils, f—Coiled wire.

Table 2-1 lists the more important alloys and metals used as resistive conductors together with their basic properties. Before selecting the material for the resistive conductor the following properties should be thoroughly understood: resistivity, temperature coefficient of resistance, mechanical strength, maximum working temperature, corrosion, aging and temperature coefficient of expansion.

1. *Resistivity*—By definition the resistivity of a material is the reciprocal of its conductivity. In more general terms, resistivity of a material is the direct-current resistance of a sample of the material having specified dimensions, the resistance being measured in ohms. The resistivity of resistive conductors is usually expressed as ohms per circular-mil-foot (Ohms/CMF).

Table 2-1 indicates that the resistivity of alloys and metals is from 10 to 800 ohms/CMF, allowing a wide range from which selection can be made. Where low resistance values are needed materials having a low value of resistivity are selected. The fact that resistance is inversely proportional to the cross-sectional area of the material should also be considered. For example, if we consider two resistive conductors of equal length and made of the same material, the one having the larger cross-sectional area will have the lower resistance.

2. *Temperature Coefficient of Resistance*—The ohmic resistances of most pure metals increase greatly with an increase in temperature as shown by the formula:

$$R_{t_2} = R_{t_1} [1 + a (t_2 - t_1)]$$

Where R_{t_2} = resistance in ohms at increased temperature

R_{t_1} = resistance in ohms at original temperature

t_2 = temperature in °C

t_1 = original temperature in °C

a = temperature coefficient of resistivity

Table 2-1 Properties of Various Metals and Alloys

Material	Resistivity at 20° C Ohms / C.M.F.	Approx. Temp. Coeff. /°C @ 20°C	Approx. Melting Point °C.	Specific Heat Gram Calories	Minimum Tensile Strength lbs. per Sq. In.
ALLOYS					
Ni Cr (75-20)	800	.00002	1350	.107	180,000
Cr Al Fe (16.5-5-78.5)	800	.0007	1480	....	90,000
Al Cr Fe (4-14-82)	680	.00026	....	....	70,000
Ni Cr Fe (64-16-20)	675	.00017	1350	....	90,000
Ni Cr (60-15)	675	.00015	1350	.107	120,000
Cr Al Fe (14.25-3.5-82.25)	675	.00016	1480	....	70,000
Ni Cr (80-20)	650	.00013	1400	....	100,000
Ni Cr Fe (35-20-45)	600	.00046	1380	.110	85,000
Ni Cr Fe (30-2-66)	500	.0007	....	....	70,000
Stainless Steel Type 304	438	.00094	1399	....	100,000
Cu Ni (55-45)	294	±.00002	1290	....	50,000
Mn Cu (13-87)	290	±.00002	1020	....	45,000
Cu Ni (30-67)	280	.0004	....	....	55,000
Monel	256	.00145	1360	....	......
18% Nickel Silver	190	.00019	1110	....	......
No. 180 Alloy (22 Ni-78 Cu)	180	.00016	1130	.092	50,000
Everdur No. 1010	155	.00034	1019	....	......
Ni Fe (70-30)	120	.0045	1425	.125	80,000
No. 95 Alloy (12 Ni-88 Cu)	95	.00038	1100	.092	......
No. 60 Alloy (6 Ni-94 Cu)	60	.00046	1100	.092	......
No. 30 Alloy (2 Ni-98 Cu)	30	.00118	1100	.092	......
PURE METALS					
Lead (Pb)	132	.0039	327	....	......
Platinum (Pt)	63.8	.0030	1755	.032	50,000
Iron (Fe)	60.1	.0050	1535	.107	50,000
Nickel (Ni)	58.0	.0050	1450	.112	60,000
Aluminum (Al)	16.06	.00446	660	.21	35,000
Copper (Cu)	10.37	.00393	1085	.92	35,000
Silver (Ag)	9.796	.0038	960	.056	42,000

A copper conductor has a temperature coefficient of resistivity (a) of approximately 0.004 at twenty degrees centigrade. This value represents an increase of resistance of 0.4 per cent per degree centigrade. Because power resistors operate at several hundred degrees above zero, it is apparent that the metals or alloys selected as resistive conductors must have much lower temperature coefficients of resistance than pure metals. This is necessary to maintain fairly constant resistance values under various load conditions and ambient temperatures.

In most instances the temperature coefficient of resistivity is positive—i.e., resistance increases with increase in temperature. In a few cases the material has a negative coefficient of resistivity—i.e., resistance decreases with increase in temperature.

As indicated in Table 2-1, most materials used as resistive conductors have positive temperature coefficients of resistivity in the order of 1.6×10^{-4}, or about 1/24-th that of copper. Using the formula, the calculated increase in resistance is approximately 5 percent for a 300°C rise. However, since the entire resistive conductor is not operating at the maximum temperature rise (300°C), the actual increase in resistance will be only about 3 to 4 percent.

In applications where a 5 percent change in resistance is unsatisfactory, the usual procedure is to use materials having approximately zero temperature coefficient. Less change also can be obtained by lowering the operating temperature of the resistor.

If these methods are used to secure close resistance tolerances, two factors must be considered. First, alloys with negative temperature coefficients of resistance and good aging and stability characteristics usually have resistivities equal to about one-half those ordinarily utilized. Thus the wire size necessary to obtain the same resistance must have one-half the area of those generally used. This, in many instances, necessitates the use of extremely fine wire sizes. Because of the low mechanical strength of the wire, such resistors become difficult to manufacture. Second, it may also mean changing the embedding coating which necessitates lowering the maximum permissible temperature rise. This, in turn, results in a larger resistor unit or use of a multiplicity of units.

Large units or assemblies of small units will naturally require more space and will be more costly than units operating at higher temperature rises.

In other applications, the resistor must have a higher temperature coefficient than normal. Materials are available that have temperature coefficients of about 45 x 10^{-4} or approximately 20 percent higher than that of copper.

3. *Mechanical Strength*—Resistive materials should have sufficient strength so that the smallest wire diameter can be wound with sufficient tension without damage, i.e., wires must be capable of being stressed without exceeding the elastic limit. They must also be able to withstand the effects of expansion and contraction caused by heating and cooling during operation.

Comparative minimum tensile strengths as measured in pounds per square inch for the various resistive materials are given in Table 2-1. When converted into ounces per circular mil, the tensile strength of No. 180 alloy becomes only about one-half an ounce per circular mil. From the example given, it is evident that materials with high tensile strength become more important where small wire sizes are used. Tensile strength is one of the limiting factors in determining the smallest diameter wire that can be used safely. On standard, power type resistors the minimum wire size is 0.001 inch in diameter.

4. *Maximum Working Temperature*—The maximum working temperature of the resistive conductor is considerably lower than its melting point. This is the temperature above which bare wire should not be used.

5. *Corrosion*—Each of the alloys listed in Table 2-1, is subject to more or less corrosion. In use, a film forms on the surface. The corrosion product may be protective; that is, it may prevent further corrosion of the metal underneath by sealing it from the air, moisture, or other damaging elements. However, most corrosion products are non-protective; that is, they are hygroscopic, flaky, porous, etc. To prevent corrosion, some form of protection, such as vitreous enamel in which the resistive conductor is embedded, is recommended.

6. *Aging*—High temperature and time have a cumulative effect on the resistive conductor. This leads to the gradual growth of the grain structure and general mechanical weakening. While most of the alloys suitable for use as resistive conductors have excellent aging characteristics, aluminum-bearing alloys, in general, are not recommended for operation at temperatures normally encountered with power type resistors.

7. *Temperature Coefficient of Expansion* — Because most materials used as resistive conductors expand when their temperatures increase, their temperature coefficient of expansion becomes an important and often critical design factor. This is particularly true when embedding coatings are used as the protecting medium. Basically the problem resolves itself into one of matching rather than one of actual control of the coefficient of expansion of the wire or ribbon. Selection of ceramics and vitreous enamels having the proper (or compatible) coefficients of expansion is the most practical means of effectively neutralizing the deleterious effects of wire or ribbon expansion and contraction. On unembedded (open or bare type) resistors, the coefficient of expansion of the resistive conductors should be as small as possible. This precaution should be taken to prevent loosening of the coils of wire or ribbon under normal operating temperatures.

C. RESISTIVE CONDUCTOR SUPPORTS.

Supports for resistive conductors, the second basic part of a resistor, are sometimes referred to as "cores" or "bases". They function, as their name implies, primarily to support the resistive wire or ribbon.

Supports for resistive conductors must of necessity be insulators because the wire or ribbon will be in contact with the supports. Moreover, the insulation properties of the supports must be maintained at the operating temperature of the resistor. In most designs, this requirement prohibits the use of ordinary organic insulations, if the full efficiency of the resistor, in so far as space and economy of materials is concerned, is to be maintained.

Table 2-2 lists the usual materials for resistive conductor supports. They include: asbestos sheet, glass, porcelain, slate, steatite and miscellaneous cold molded or vitrified inorganic materials. The insulating proper-

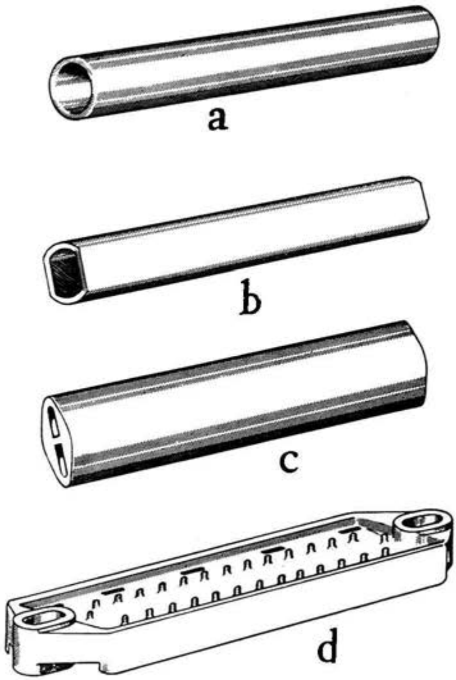


Figure 2-2a. Typical Forms of Supports for Resistive Conductors
a—Tubular ceramic core, b—Tubular ceramic core—with flat sides, c—Oval shaped ceramic strip, d—Flat molded ceramic—rectangular shape.

ties of some of these materials while decreasing due to increase in temperature, are sufficiently high for commercial use.

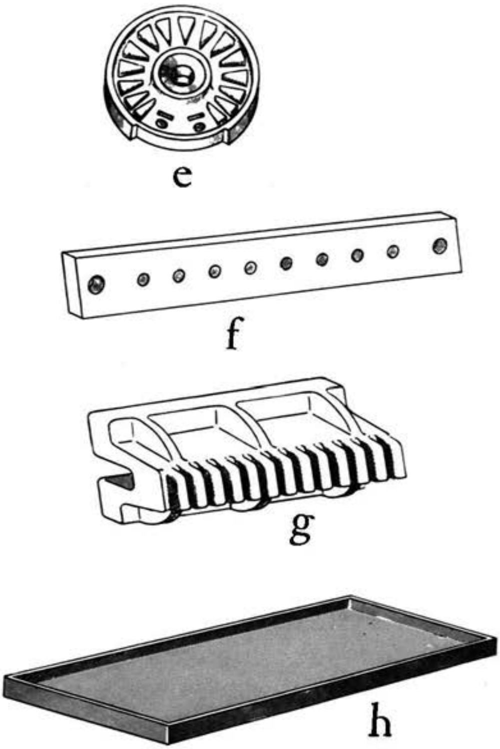


Figure 2-2b. Typical Forms of Supports for Resistive Conductors
e—Flat molded ceramic—circular shape, f—Ebony asbestos strip, g—Grooved ceramic strip, h—Pressed steel pan—vitreous enamel insulated.

Materials For Resistors

It should be realized that materials listed as inorganic and with suitable heat resistant qualities, have the undesirable characteristic of low mechanical strength.

However, by the judicious design and control of manufacturing processes, the strength of available materials can be held at a maximum. Other support design precautions that should be taken to maintain ample mechanical strength are:

1—Make the unit as small as possible.

2—Avoid cantilever construction.

3—Avoid long beam lengths on small diameter tubes.

The material's coefficient of expansion should be compatible with that of the resistive conductor and the protective coating. This is necessary to prevent cracking, peeling or layer separation under temperature changes. It is also imperative that binders used in molding materials, organic compounds, and cements, be unaffected by operating temperatures. There should be no weakening of the structure or softening or cracking of the material.

The shape of the resistive conductor support, which may take the form of rods, cylinders, strips, etc., is determined largely by the type of resistor and ratings required. Several common shapes for resistive conductor supports are shown in Figure 2-2. Other support forms are illustrated in photographs accompanying Chapter III, TYPES OF RESISTORS. Of all the forms shown, the most widely used for power resistors are cylinders of various sizes. These are made by extrusion of ceramic material which is then cut to length and fired at high temperatures to vitrify the material. This process, explained in more detail in Chapter VI, results in a support that is straight, strong and uniform in size and shape.

In tubular resistors, since the circumference of the supporting core determines the length of wire that can be wound on a given length unit with specified pitch, close core tolerances are essential to secure accurate resistors.

Table 2-2 Constants of Various Materials Used For Supports

Properties	Bakelite	Commercial Lime Glass	Electrical Porcelain	Steatite Vitreous Ceramic	Cold Molded Transite Portland	Ebony Asbestos
Specific Gravity	1.79-2.09	2.41-2.81	2.5	2.5	1.66-1.80	2.04
Tensile Strength, lb. per sq. in.	5,000-10,000	10,000	7,500	6,500	900-1,200	3,000
Compressive Strength, lb. per sq. in.	18,000-36,000	180,000	80,000	75,000	8,000-12,000	15,000
Impact Strength, ft. lb. per sq. in.	1.4-4.5	42% higher than tensile strength	1.8 Charpy	1.6 Charpy	...	...
Modulus of Elasticity, lb. per sq. in. x 10^5	10-45	100	145	...	...	...
Modulus of Rupture, lb. per sq. in.	...	...	21,000	20,000	4,000-5,000	5,500
Thermal conductivity, 10^{-4} Cal. per sq. cm. second	8-20	22.3	24.8	...	...	...
Linear expansivity, 10^{-5} per °C	2	1.07	0.35	0.637	...	...
Specific heat, cal. per °C, gram	0.25-0.35	0.18	0.26	...	...	...
Heat resistance, °F	400-500 max. operating	1238-1382 softening	2400-2900 softening	2606 softening 1832 max. safe	700 recommended working temperature	300 max. safe working temperature
Water absorption, % wt. 48 hrs.	0.01-0.15	...	...	0.03-max. extruded	15-24	...
Volume resistivity, Megohms per cm. cube	10^3-10^5	9x10^7	3x10^8	10^8	...	...
Breakdown voltage, volts per mil.	250-400	203-229	200	200	...	100
Dielectric Constant, at 10^6 cycles	4.5-20	5.5-9.1	4.4	6.2	...	...
Power Factor, radio frequencies	0.05-0.10	...	...	0.002	...	...

D. TERMINALS.

Resistor terminals, Figure 2-3, perform several important functions. They afford a means of electrical connection to the resistive conductor. Terminals, therefore, should have excellent conductive and corrosion resistant qualities. Because of their close proximity to the resistive conductor which operates at high temperatures, connections must not be adversely affected by these temperatures, either by the formation of insulating oxides or other changes in physical characteristics.

Terminals may serve to hold the resistive conductor in place. For example, on tubular wire wound resistors, the ends of the resistive conductor are secured to terminal bands and thereby anchored in place. Since the terminals are partially embedded in the protective coating (vitreous enamel) it is important that the thermal expansion characteristics of the terminal material be "matched" with that of the embedding material. This is necessary to prevent cracking of the coating and unsatisfactory sealing of the unit about the terminals.

On tubular resistors the connection point or joint between the resistive conductor and the terminal should be silver brazed. The high melting point of silver solder is particularly advantageous because it precludes any possibility of the joint softening when the resistor is operated at rated load. The joint formed by silver brazing also provides a superior mechanical and electrical connection.

Certain terminals sometimes serve as a means of mounting the resistor. Terminals should have ample mechanical strength to avoid damage when connecting external wiring. Where external connections must be soldered to the resistor terminals, materials should be selected that can be readily soldered. Terminals designed for soldering connections are generally tinned during manufacture as an aid in soldering.

The exact method of securing terminals to the support and resistive conductor, and the determination of

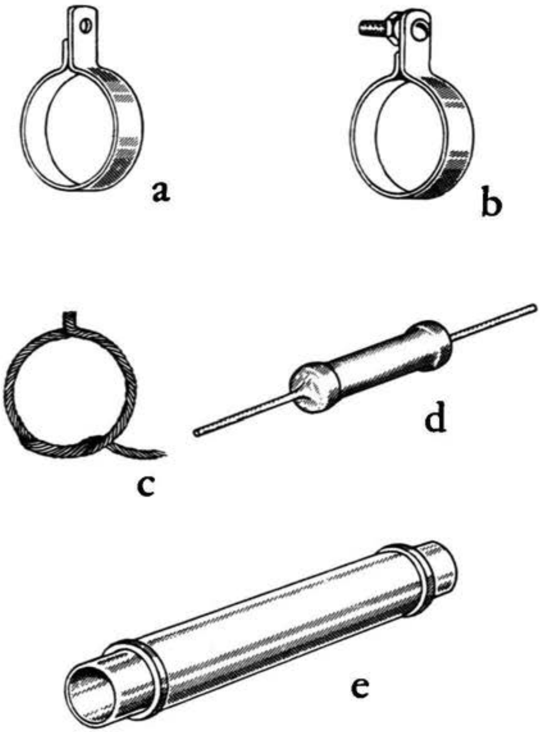


Figure 2-3a. Typical example of Resistor Terminal Connections
a—Tab terminal, b—Screw type, c—Stranded wire, d—Axial wire solid, e—Ferrule or band.

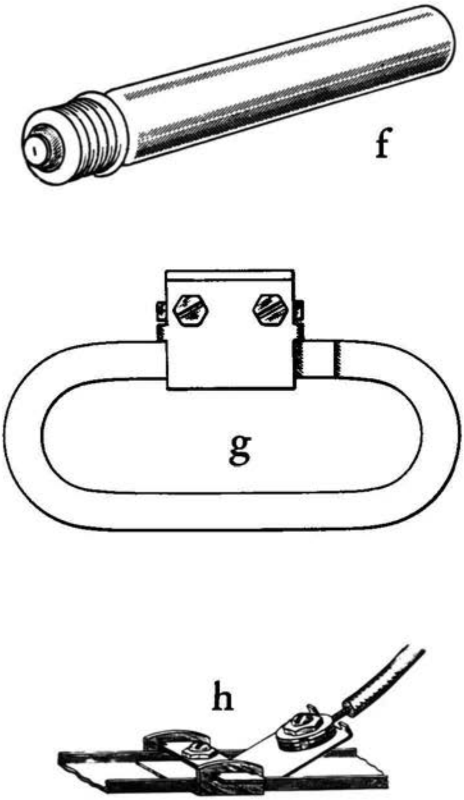


Figure 2-3b. Typical examples of Resistor Terminal Connections
f—Edison screw base, g—Clamp type, h—Adjustable clamp.

the best type terminal, depends essentially on the type of finished resistors. Further details on the common types of terminals are discussed in Chapter III, TYPES OF RESISTORS.

E. PROTECTIVE COATINGS.

Because of the detrimental effects that adverse atmospheric conditions have on the resistive conductor, some forms of power resistors, usually wire-wound types, are fully sealed and protected by some kind of embedding material. The coating applied depends on the resistor operating temperature, extent of protection needed, and service requirements as to thermal shock, moisture, humidity and insulation.

The wide variety of protective coatings includes: vitreous enamels, organic and inorganic cements, organic paints and varnishes, and silicone paints and varnishes. Because coatings used vary with each manufacturer, only general requirements will be discussed in subsequent paragraphs.

1. *Thermal Conductivity*—When the resistive conductor (wire) is embedded, the heat generated by the wire must be conducted to the air either through the resistor core or through the protective coating. The operating temperature of the wire is determined by the degree to which the embedding material and core are able to conduct the heat. Therefore, materials with high thermal conductivity characteristics should be chosen. If materials having poor thermal conductivity qualities are used, the life of the resistor is shortened.

2. *Radiation and Convection*—Once the heat is conducted to the surface of the resistor, it is dissipated by radiation and convection. The thermal radiating or emissive qualities of materials vary greatly and are independent of air circulation. As the resistor surface temperature increases, the effect of heat dissipation by radiation become increasingly important.

Convection resulting from circulation of air over the resistor surface carries a large portion of the heat away. The amount of heat dispersed by convection depends essentially on the temperature and rate of flow of the cooling air and on the resistor surface area.

3. *Thermal Shock*—Protective coatings must be capable of withstanding thermal shock, that is, sudden marked changes in ambient temperature such as encountered in service. Excellent thermal shock characteristics though necessary for continuous duty become even more important where the resistors are used in intermittent-duty circuits where high momentary overloads are encountered.

4. *Thermal Expansion* — Thermal expansion characteristics of the protective coating should be favorable, i.e., "matched" to the thermal expansion characteristics of all other resistor parts. This condition must exist over the entire operating temperature range of the units. Coatings should also adhere firmly to the wire, core and terminals without peeling, cracking or flaking during operation.

5. *Mechanical Protection*—One of the main reasons for embedding the wire, as mentioned previously, is to supply adequate mechanical protection, especially when fine wire sizes are used. The coating not only protects the resistive conductor, but also the terminal band and silver-brazed joint between the wire and the terminal band. Protective coatings provide a secondary function, that of holding the wire and terminals securely in place.

6. *Corrosion*—Protection against the damaging effects of corrosion is another vital function of embedding materials. In general, coatings used should be resistant to moisture and acid fumes, and for some applications salt spray. To accomplish this, coatings should be free from cracks, crazes, pinholes and other openings that would allow corrosive atmospheres to reach the wire.

7. *Insulation*—Protective coatings must provide adequate insulation between turns of the winding to prevent short circuits during high voltage surges.

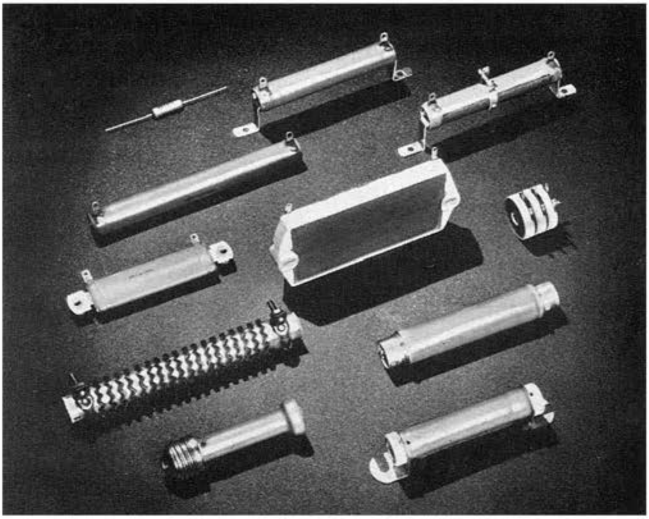


Figure 2-4. Typical Vitrohm wire-wound power resistors.

CHAPTER III

Types of Resistors

A. VITROHM TUBULAR RESISTORS.

Today's standard resistors for power applications are Vitrohm resistors, developed by the Ward Leonard Electric Co. over half a century ago. These vitreous enameled, wire- and ribbon-wound resistors are manufactured in a wide variety of types and sizes to meet virtually every industrial, commercial and military power resistor requirement. Of all the types available Vitrohm units of the tubular type are most in demand.

1. *Construction*—A Vitrohm resistor, Figure 3-1, consists basically of a tubular ceramic core on which the resistive conductor is wound and the ends of which are secured to metal terminals by means of spot welding. The resistive conductor and the band portion of the terminal are then completely covered by vitreous enamel. Although the general construction of other manufacturers' products is similar to that of a Vitrohm resistor, there are major differences in method of manu-

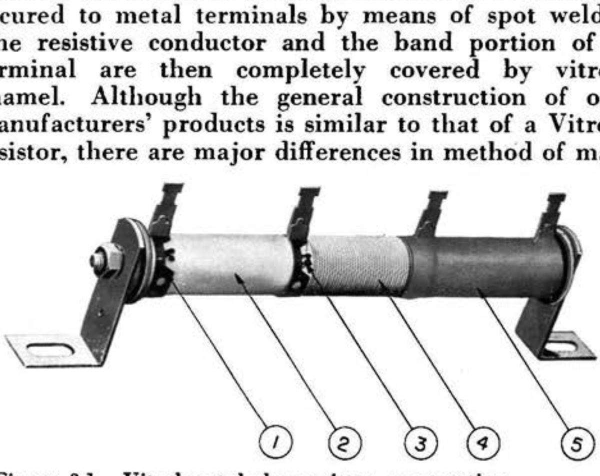


Figure 3-1. Vitrohm tubular resistor construction
1—Terminals and band, 2—Tubular ceramic core, 3—Spot welded or silver brazed joint,
4—Alloy resistive conductor, 5—Vitreous enamel protective coating.

facture. The following analysis of each of the basic components which go into the manufacture of the finished Vitrohm resistor will show why Vitrohm resistors are industry's standard power resistor.

a. Ceramic core—The tube for the Vitrohm resistor is a high density, low porosity (less than ½ percent moisture absorption maximum), high dielectric-strength body with a thermal coefficient of expansion selected to have the correct relation to the expansion of the Vitrohm enamel. The ceramic core is cylindrical with smooth surface and square ends.

b. Terminals—Terminals of the Vitrohm resistor are of high-heat-resistant, high-tensile-strength alloy especially selected to insure proper expansion, good adherence to the enamel and to provide the strongest anchorage to the ceramic core. They are clamped securely to the core by welding.

c. Resistive conductor—Resistance wire used in the Vitrohm resistors is especially manufactured to Ward Leonard specifications to insure uniformity and ability to withstand excessive overloads. A wide variety of alloys is employed depending upon the service requirements for each type of resistor.

d. Joint—The junction between resistive conductor and terminal is of extreme importance in any resistor. The Vitrohm resistor joint is made by spot welding or silver brazing to insure a permanent, positive, low-resistance junction between resistive conductor and terminal.

e. Protective Coating—Vitrohm enamel (developed and manufactured exclusively by Ward Leonard) is a hard, tough, moisture and acid resisting vitreous enamel with high heat conductivity. It completely seals the resistive conductor from all contact with injurious elements. At the same time it provides excellent mechanical protection to the resistive conductor, the joint and the terminals. It is fired at high temperature during the manufacturing process. In operation, resistors are never subjected to such conditions. In other words, the finished Vitrohm resistor has already withstood, during manufacture, a more severe test than will ever be encountered in normal service.

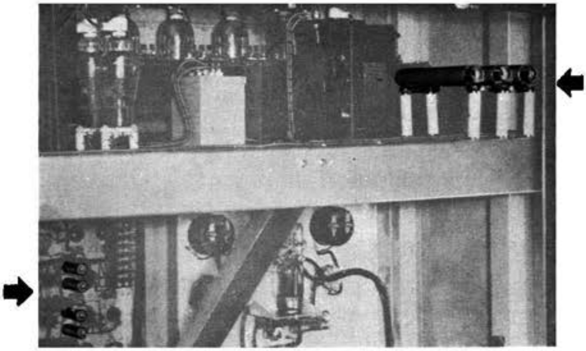


Figure 3-2. Vitrohm Power Resistors installed in WOR-TV transmitter, N. Bergen, N. J. Vitrohm Ferrule Terminal Resistors with high voltage mounting, upper right, are for bleeder purposes.

The Vitrohm enamel that hermetically seals the resistive conductor, also possesses characteristics which withstand rapid changes in temperature. For example, units operating at 340°C can be immediately placed in a chamber at –55°C without any chipping or crazing of the enamel or damage to the element. Vitrohm enamel can equally withstand the effects of prolonged exposure to high humidity and electrolysis. Vitrohm resistors will stand up in an atmosphere of 95 percent relative humidity with a potential gradient of 120 volts D. C. between the resistive conductor and a metal plate to which the resistor is bolted without supplementary insulation. They will withstand a repeated heating and cooling cycle from 340° to 20°C without any effect upon either the enamel or the resistive conductor.

Ward Leonard produces its own Vitrohm enamel and ceramics. The majority of other vitreous enamel resistor manufacturers buy their enamel and ceramics from outside sources. Two factors are important here:— First, Vitrohm enamel and ceramics are developed and manufactured expressly to match each other and to be compatible with the wire and terminals. Only by controlling the enamel and ceramic and selecting the proper wire and terminal materials can the proper relationships of the coefficients of expansion be maintained. Second, by making each component, the uniformity of quality is assured. Every batch of enamel is tested for thermal expansion, softening point, flow point and texture before release for production. The same control applies to the

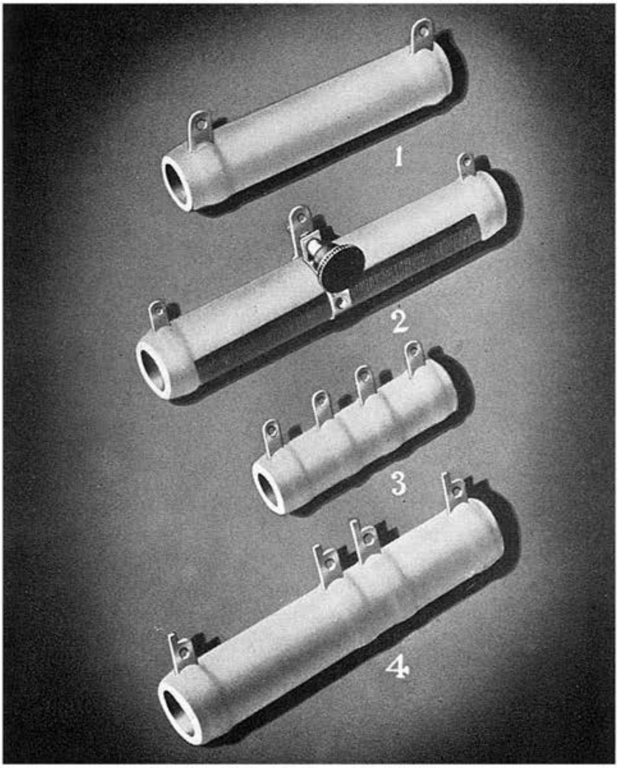


Figure 3-3. Basic forms of Vitrohm tubular resistors
1—Fixed, 2—Adjustable, 3—Tapped, 4—Multi-section.

ceramic material from which the resistor cores are extruded.

2. *Forms*—Four basic forms of Vitrohm tubular resistors, Figure 3-3, are available to the design engineer.

(1) Vitrohm fixed resistors are resistors of a single winding with tab, screw, flexible-lead, ferrule, Edison base, or fire-panel terminals.

(2) Adjustable Vitrohm resistors have terminals the same as fixed resistors but, in addition, have the wire winding exposed in a path along one side so that an adjustable band may be affixed and moved along the length of the exposed wire to adjust resistance as desired.

(3) Tapped Vitrohm resistors are fixed units with an extra terminal or terminals at predetermined points along the tube. The terminals, at desired points, are provided for voltage division or adjustment.

(4) Multi-Section Vitrohm resistors are arranged similarly to tapped units except that with this arrangement two or more electrically independent resistor sections may be obtained with a single resistor assembly. Two terminals are required for each section and a space without resistance winding separates each independent section.

3. *Terminals*—Determination of the best type terminal for a Vitrohm resistor should be based on the following considerations:

(1) Rating, type and physical size of the resistor.
(2) Method of connection — soldering, machine screws, fuse clips, etc.
(3) Method of mounting.
(4) Allowable space and accessibility.
(5) Size and type panel wiring.
(6) Creepages and clearances to ground or other "live" parts.

(7) Ambient temperature and other application conditions such as vibration and excessive humidity.

Figure 3-4 illustrates several types of terminals for Vitrohm Resistors.

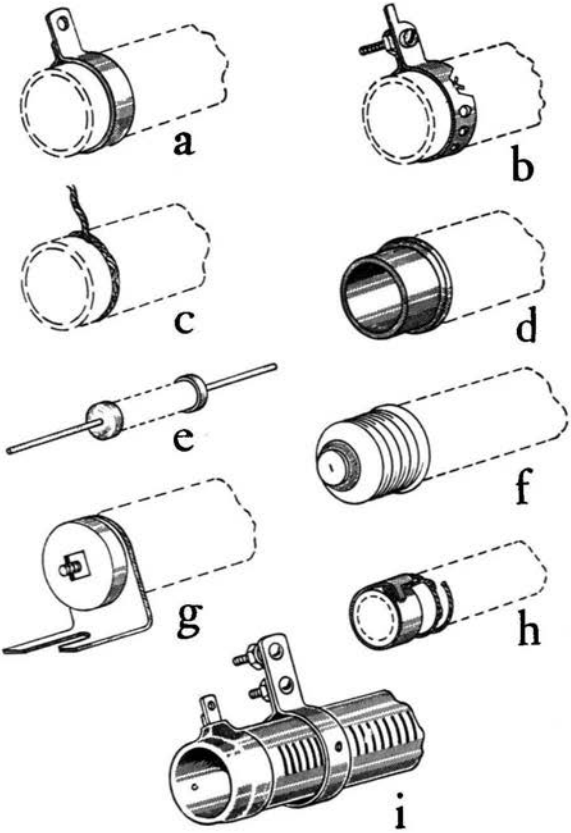


Figure 3-4. Typical Types of Vitrohm Resistor Terminals
a—Tab, b—Screw-type tab, c—Flexible wire lead, d—Ferrule, e—Axial, f—Edison base, g—Bracket, h—Band, i—Adjustable band.

Types Of Resistors

a. Tab or lug terminals are recommended where the wiring leads must be soldered. These metal tabs, usually pre-tinned for easy soldering, are made in standard widths from $\frac{3}{16}$ inch to ½ inch and with various size holes to accommodate different wire sizes. The wider, heavier weight tabs should be used with the larger size tubes.

b. Screw-type tab terminals are intended for use where heavy leads are brought to the resistor and are fastened directly by fastening between the nuts that accompany the screw connections. Like solder tabs those of the screw type are available in a number of sizes to facilitate use of various size control circuit wiring and solder or solderless lugs.

c. Pigtail or flexible-lead terminals are especially suited for connecting the resistor directly to other circuit components by means of the flexible leads. Leads are ordinarily tinned and uninsulated.

d. Ferrule terminals should be selected for ease of interchangeability where it is necessary to change the resistance value in a circuit. Ferrule terminal resistors are supplied for use with 0-30 ampere or 31-60 ampere, 250 volt fuse clips or 31-60 ampere, 600 volt fuse clips.

e. Axial terminals serve two purposes, namely, a means of connection and a means of mounting the resistor. The solid wire leads are normally tinned for convenience in soldering.

f. Resistors with Edison base terminals are screwed into standard lamp sockets. They are advantageous in applications such as load banks, battery charging equipment and other apparatus requiring an easy means of changing resistance.

g. Another terminal used where interchangeability is necessary, such as on fire and signal panels, is the bracket terminal. Leads from the resistive conductor are silver brazed to the slotted brass brackets. The brackets, which also serve as a means of mounting the

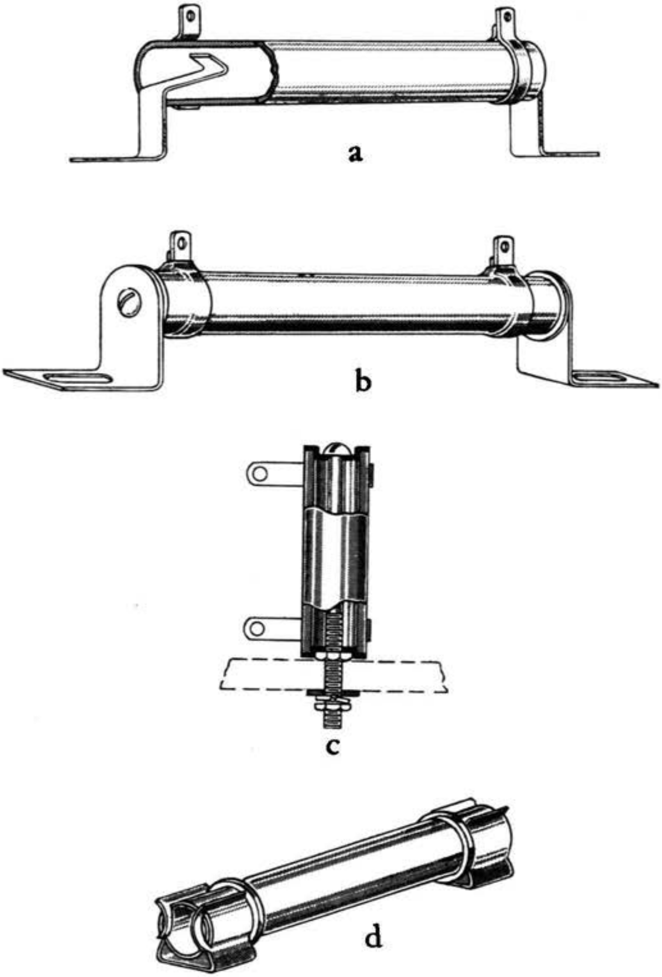


Figure 3-5a. Typical Methods of Mounting Vitrohm Tubular Resistors

a—Push-in spring clips, b—Through bolt—horizontal, c—Through bolt—vertical, d—Ferrule—fuse clips.

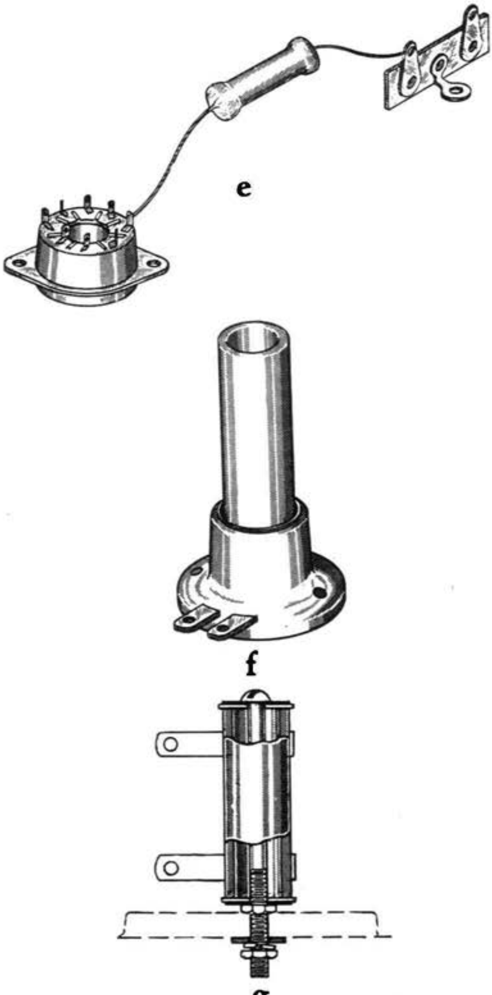


Figure 3-5b. Typical Methods of Mounting Vitrohm Tubular Resistors

e—Self-supporting, f—Edison Base, g—Through bolt vertical with mica washers.

resistor, are held in place by a through bolt that is insulated from the brackets by means of porcelain bushings. They may also be equipped with anchors and cemented into the ends of the resistor.

h. Band ferrule terminals, like the ferrule type, require fuse clips for connection and mounting purposes.

i. Adjustable bands for use in Adjustohm or bare-side resistors should be specified where one or more intermediate resistance values are needed, or where the circuit resistance must be changed from time to time. Screw-driver type or bakelite insulating knob type adjustable bands are available.

4. *Mountings*—Many of the selection factors discussed under "*Terminals*" must also be analyzed in choosing the proper type mounting for a resistor. For example, the number and type of resistors together with the space allowance and application conditions all must be considered.

Several typical ways of mounting Vitrohm tubular resistors are shown in Figure 3-5. For the average commercial or industrial application push-in spring clips are used and are generally considered satisfactory. A second method of mounting single tubes horizontally is by means of through bolts, mica washers, centering washers and L-shaped brackets. For vertical mounting through bolts and centering washers are used. On high-voltage applications mica washers or ceramic bushings should be used. Where accessibility and quick replacement is desirable, ferrule (fuse clip), Edison base or bracket terminal mountings should be used. For mounting two or more resistors, through-bolt bracket mountings should be used. Through-bolt bracket mountings should always be specified where the equipment will be subjected to shock or vibration. Special bracket mountings are required for high-shock military requirements.

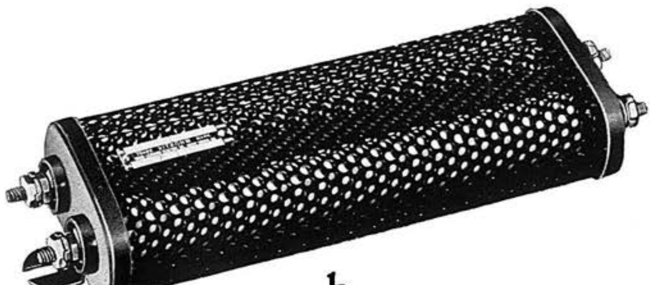
5. *Enclosures*—Several typical enclosures for housing single or multiple resistor units are illustrated in Figure 3-6. These enclosures are constructed of expanded or

perforated metal and are rectangular, oval or circular in shape. Most types can be equipped with removable metal tops, BX connectors, external terminal connections and other features to meet application requirements.

Besides protecting resistors against mechanical damage, enclosures prevent accidental contact with "live" parts.

When mounting enclosed resistors, locations where ventilation is restricted should be avoided. When resistors are enclosed, singly or in groups, their nominal watt rating must be reduced. See page 62 for information on derating for enclosures.

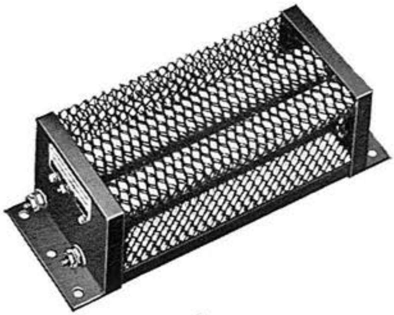
a



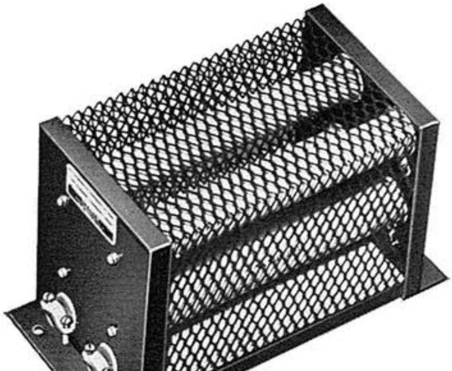
b

Figure 3-6a. Typical enclosures for Vitrohm Resistors
a—Circular shaped perforated metal, b—oval shaped perforated metal.

c



d



e

Figure 3-6b. Typical enclosures for Vitrohm Resistors
c—Adaptor enclosure, d—Rectangular metal mesh with screw terminals, e—Rectangular metal mesh with BX connector.

6. *Ratings*—The free-air watt ratings of Vitrohm tubular resistors range from 5 to 218 watts per unit. Resistance values from 0.2 to 1,750,000 ohms are obtainable. Nominal core lengths are from 1 to 12 inches, while outside diameters range from $\frac{5}{16}$ to $1\frac{1}{8}$ inch. Inside diameters of Vitrohm tubes are listed in Table 3-1. The type of tube is designated by a letter, i.e., Z, O, WX, etc. Each tube of a specified outside diameter is available in several standard lengths as shown in Chapter V, page 124.

Table 3-1 Inside Diameters of Vitrohm Ceramic Tubes (Inches)

Tube Type	O. D. Nom. (Inches)	INSIDE DIAMETER (Inches)		
		Nom.	Min.	Max.
Z	$\frac{5}{16}$	.219	.202	.236
O	$\frac{7}{16}$	.312	.293	.331
T	$\frac{9}{16}$	.393	.369	.417
A	$\frac{5}{8}$	.455	.429	.481
B	$\frac{3}{4}$	.540	.508	.572
WX	$\frac{15}{16}$	.562	.516	.609
D	$1\frac{1}{8}$	.750	.699	.801

Note: Above tolerances do not make allowances for longitudinal curvature.

7. *Resistance Tolerance*—On Vitrohm fixed and adjustable resistors from 1 ohm to maximum possible ohms, the standard resistance tolerance, measured from one end terminal to the other, is ± 5%. The tolerance on adjustable resistors is measured without the adjustable band. For values below one ohm and for tapped resistors the standard tolerance is ± 15%.

Other tolerances as low as ± 0.5% are available at increased cost. On tubes having short nominal lengths close tolerances should be avoided wherever possible.

8. *Performance Data*—Accurate resistor performance data is particularly valuable for determining the useful life of a resistor under average as well as adverse application conditions. Such information must often be obtained before final selection of the proper type resistor can be made. Some of the tests that are performed on Vitrohm wire-wound power-type resistors include: momentary overload, heating and cooling, humidity, vibration, mechanical strength, mechanical shock, salt water immersion, thermal shock, salt spray corrosion, insulation resistance and dielectric strength.

The primary purpose of these tests and the basic test procedure used, as well as test results on representative production samples, will be discussed in subsequent paragraphs.

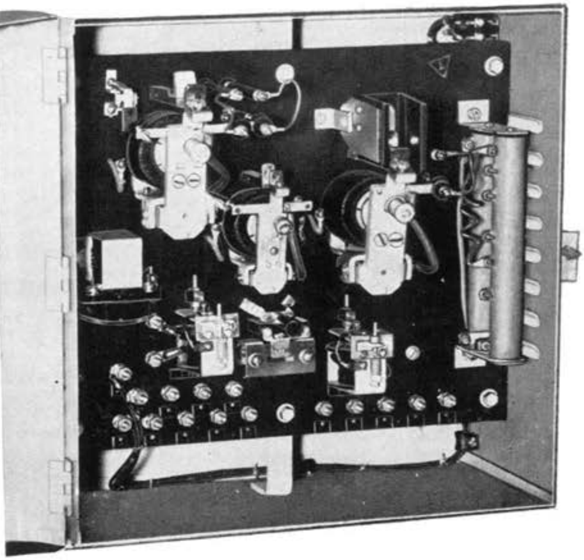


Figure 3-7. Special D.C. Motor Controller. Tapped Tubular Resistor, at right, is for adjusting motor field currents and presetting motor speed.

a. Momentary Overload Tests—These short-duration overload tests are used to determine the ruggedness, strength and durability of the resistive conductor and protective coating when subject to extreme amounts of energy for a short time.

In making momentary overload tests, the resistance of the resistor is measured and recorded at room temperature. Next, a voltage corresponding to 10 times rated wattage is applied to the resistor for 5 seconds, or for the time required for the hot spot to reach maximum allowable temperature. The voltage applied should not be in excess of 6,000 volts. This maximum voltage was chosen to eliminate the danger of handling high voltage above 6,000 volts. After the power source is disconnected the resistor is allowed to cool to room (ambient) temperature. When cool the resistor is given a visual inspection for charring, burns, or signs of arcing, chipping, crazing, etc. Finally, the resistance is again measured, recorded and compared with initial values.

Results of the momentary overload test on Vitrohm, fixed, tubular resistors show that no damage occurs to any part of the resistor, and that the change in resistance value is less than ½ of 1 percent.

b. Heating and Cooling Tests—These tests serve a dual purpose. First, they indicate, in part, how resistors will perform under intermittent-duty conditions. Second, they are useful for determining the length of time required for a resistor to reach maximum temperature under various load conditions, and conversely for revealing the time required for a resistor to reach ambient temperature after the maximum temperature has been attained.

The curves of Figure 3-8 compare temperature rise versus time characteristics of an 8½″ D, 160-watt, 150-ohm, Vitrohm resistor when subjected to various loads.

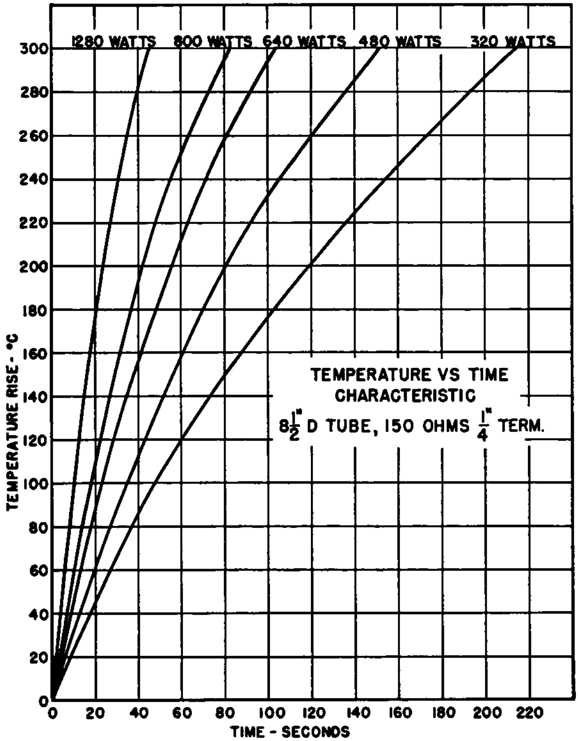


Figure 3-8. Temperature vs Time Characteristic

On application of a voltage to attain 320 watts, the time interval to achieve a maximum temperature rise (300°C) is about 3 minutes 35 seconds. Note in the 480, 640, 800 and 1280 watt tests that the time taken to reach a given temperature rise decreases as the wattage impressed on the tube is raised.

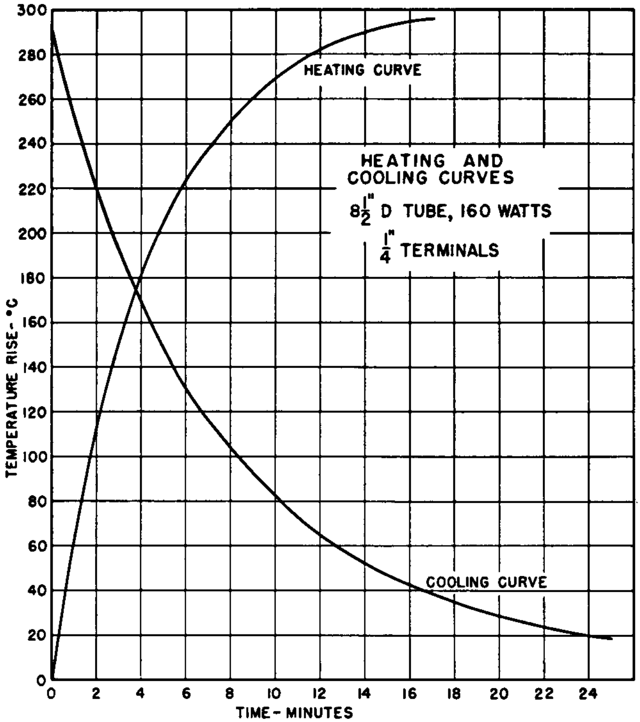


Figure 3-9. Heating and Cooling Curves

The heating time required for a resistor to reach maximum temperature rise depends mainly on:

(1) Wattage dissipated.
(2) Mass of the unit.
(3) Its specific heat characteristics.
(4) The emissivity properties of the materials used.

If a resistor having a thinner core with finer wire embedded in a coating of higher emissivity characteristics were used, the time intervals to attain maximum temperature rise would be lowered accordingly.

Figure 3-9 shows the relationship between the heating and cooling curves for an $8\frac{1}{2}''$ D Vitrohm resistor rated at 160 watts. On placing a voltage across the resistor to dissipate full nominal watts (160), the time to reach a temperature rise of 292°C is shown as 17 minutes. Although not shown in Figure 3-9 the heating curve levels off, reaching stabilization (300°C) in about 30 to 45 minutes. Notice that the cooling cycle, i.e., time required for the resistor to reach room temperature is considerably longer than the heating cycle. When the tube is heating the differential between ambient temperature and resistor temperature becomes greater, whereas during the cooling cycle the differential becomes less, since the cooling medium remains constant.

c. Humidity—Where resistors are used in tropical climates or other excessively humid locations, their ability to withstand high humidity must be determined. To do this, the resistors are subjected to the temperature and humidity cycles shown in Table 3-2.

Steps 1 and 2 are performed only at the beginning of the test. Step 1 is the initial drying period. The resistance and insulation resistance of the resistors are measured during the last half hour of Step 2 and at the end of Step 9. The resistors are then subjected to the cycling beginning with Step 3.

During the first two hours of Steps 3 and 6, the rated load is derated to the temperature obtained at the end of the two hour period in accordance with Figure 3-10, and is applied to each resistor from Step 3 through Step 8. During Steps 4, 5, 7 and 8, 100 volts D.C. is applied with positive connected to the resistive conductor and negative connected to the mounting hardware. During Steps 10, 11, 12 and 13, the resistors are

Table 3-2 Humidity Test for Resistors

Step Number	Ambient Temperature Degrees C	Relative Humidity Per Cent	Time Hours
1	40	not controlled	24
2	25	50	2½
3*	25 to 65 transient	90—95	2½
4	65	90—95	3
5	65 to 25 transient	90—95	2½
6	25 to 65 transient	90—95	2½
7	65	90—95	3
8	65 to 25 transient	90—95	2½
9	25	90—95	1¾
10	25 to −10 transient	not controlled	½
11	−10	not controlled	2¼
12**	−10 to 25 transient	not controlled	½
13	25	90—95	3

*Steps 3 to 13 constitute a single 24 hour cycle.
**Followed by vibration test for 15 minutes.

returned to the humidity chamber. Within 15 minutes after the completion of Step 12 the resistors are subjected to a vibration test for 15 minutes.

Test results on typical Vitrohm resistors manufactured specifically for this type service indicate that they are unaffected by this severe test after more than 80 cycles.

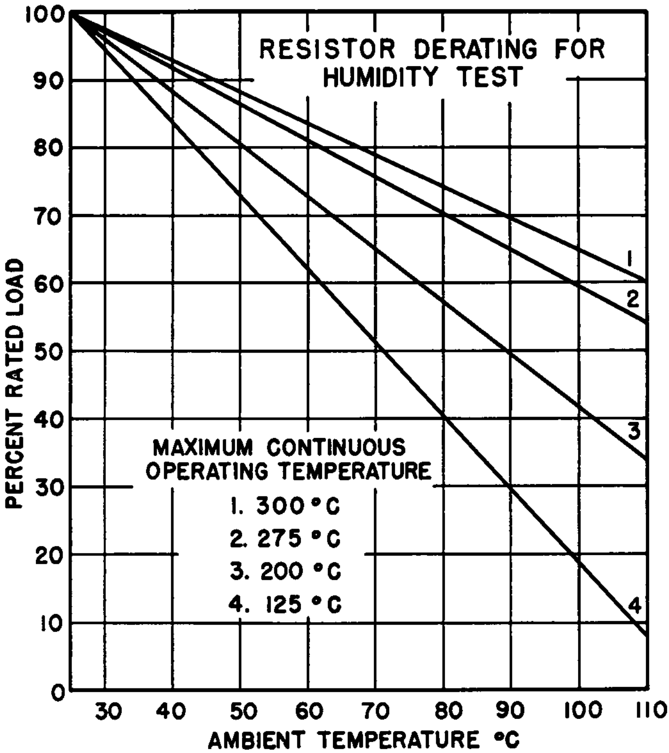


Figure 3-10. Resistor Derating for Humidity Test

d. Vibration — When resistors are mounted in equipment or locations where excessive vibration occurs, they must be constructed so as to avoid damage. In making vibration tests the resistors with their mounting brackets in place are subjected to a simple harmonic motion (amplitude of at least 0.03 inches, total excursion 0.06 inches, frequency varying from 10 to 55 cycles). The 10- to 55-cycle frequency range is traversed every minute for five hours. Then the resistors are checked for change in resistance value and for signs of damage such as cracks, loose parts, etc.

Vitrohm tubular resistors after being subjected to the vibration test show no noticeable signs of cracks or other flaws. Change in resistance value is less than ½ of 1 percent.

e. Mechanical Strength—To make sure that resistors will be able to withstand normal abuse in handling, they are tested for mechanical strength. In this test they are supported ⅛ inch from each end and a transverse load is applied to the center of the resistor through a beam having a radius of contact of not less that 0.25 inches.

Vitrohm tubular resistors are capable of supporting loads of from 250 to 500 pounds.

f. Mechanical Shock — On portable and mobile equipment, especially in military applications, resistors must be capable of withstanding mechanical shock without damage to component parts.

In these shock tests, the resistor (or group of resistors) is subjected to several blows parallel to the principal axes of the resistance unit or assembly.

The ability of a resistor to withstand shock depends not only on the construction of the resistor but also on the method of mounting used. For example, on ferrule resistors additional clamps must be provided to prevent the resistor from disengaging the fuse clips under mechanical shock. Edison base resistors should be avoided where shockproof construction is desired. Tubes with short nominal lengths are recommended over those with long nominal lengths.

Vitrohm tubular resistors when equipped with suitable mountings are capable of withstanding numerous blows of from 150 up to 2,000 foot-pounds.

g. Salt Water Immersion—Where resistors are to be used for shipboard and similar applications, they can be furnished with special coatings, and their ability to withstand salt water is determined by the cyclical test.

A single cycle is as follows: Rated power is applied for 2 hours, and the resistance is measured. Within 5 seconds after the removal of potential, the resistor is immersed for 1 hour in a saturated salt-water bath maintained at 100°C ± 4°C. Within 5 seconds after removal from this bath, the resistor is immersed in another saturated salt-water bath maintained at 0°C $^{+5°}_{-0°}$ C for a period of 1 hour. The resistor is then thoroughly and quickly washed in tap water and all surfaces (external and internal) wiped dry and clean or air-blasted. The resistor is then operated at rated power for 2 hours, and the resistance is again measured.

Vitrohm tubular resistors made expressly for this type of service can successfully withstand at least 9 cycles of the above test.

h. Thermal Shock—Because resistors are frequently used in applications where the air temperature varies over wide limits (for example, airborne equipment) their thermal shock characteristics must be determined.

In thermal shock tests rated power is applied to the resistor until thermal stability has been reached. The power is then removed and the resistor is immediately subjected to a temperature of —55°C for at least 15 minutes. Then the unit is checked for resistance and is inspected for mechanical defects.

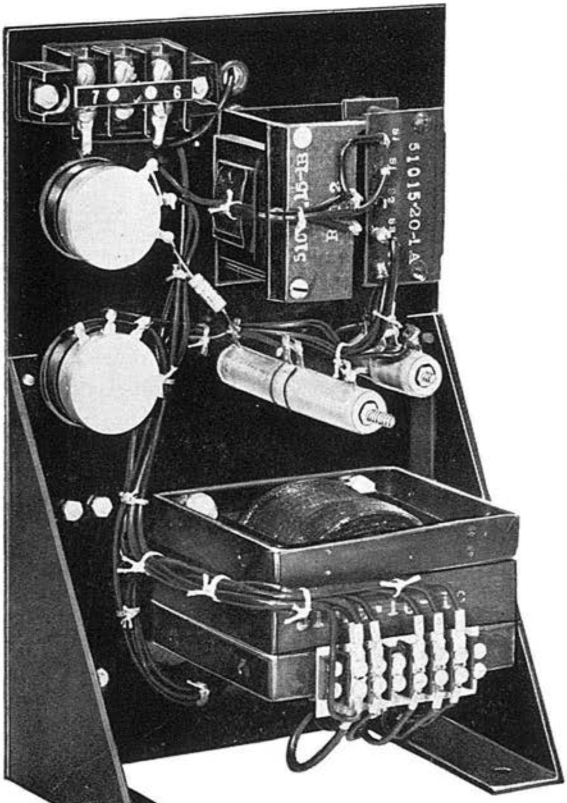


Figure 3-11. Rear View of Hysterset Electronic Lamp Dimmer Control Using Vitrohm Fixed and Adjustable Resistors

For applications where the resistors are likely to come in contact with liquids such as water, resistors are sometimes given another thermal shock test. In this test the heated resistor (as outlined in the preceding paragraph) is plunged into tap water at 0°C $^{+5°}_{-0°}$ C for one minute.

After the above tests Vitrohm resistors show no defects in the embedding coating or other parts that would result in unsatisfactory performance. Change in resistance value is less than ½ of 1 percent.

i. Salt Spray Corrosion—Another test used to determine the ability of resistors to withstand marine conditions is as follows:

The resistor is suspended in a closed chamber and subjected to a continuous spray under a pressure of 25 pounds per square inch of a salt solution whose specific gravity is 1.151 at 16°C and whose temperature is 35°C.

After being subjected to the above tests, Vitrohm resistors show no noticeable evidence of deterioration after 100 hours. Resistance values change less than ½ of 1 percent from initial values.

j. Insulation Resistance Test — This test is performed on resistors to determine the leakage current from the terminals to the mounting hardware.

In making the insulation resistance test on a resistor (except ferrule type), the resistance between the resistor terminals connected together and the mounting brackets is measured using a D.C. potential of 100 volts.

The resistance of the insulation of Vitrohm tubular resistors is infinite under standard test conditions.

k. Dielectric Tests—These high voltage tests are performed on resistors to determine the ability of the insulating materials and spacings used to withstand breakdown.

In making dielectric tests on single resistors, except those of the ferrule or axial-terminal type, a high voltage having a frequency not less than 60 cycles, and approximating a true sine wave, is applied between the resistor terminals and the mounting brackets. The exact voltage applied depends on the voltage rating of the resistor. On resistors designed for use on equipment rated 600 volts and below, an RMS voltage of twice rated volts plus 1,000 volts is applied for at least one minute. Where the equipment is rated over 600 volts, the dielectric test voltage is $2\frac{1}{4}$ times the rated voltage plus 2,000 volts.

9. *Application Data*—When applying embedded wire-wound power-type resistors, the following essential characteristics should be known:

(1) Load versus temperature rise

(2) Grouping and spacing

(3) Derating factor for enclosures

(4) Voltage on unit

(5) Duty on unit

a. Load versus Temperature Rise—The curves of Figure 3-12 show the temperature rise that can be expected at any load from zero to 100 percent of rated load for resistors whose nominal rating is based on a 250°, 300° or 375°C rise as measured under standard test conditions with one foot of free air space around the resistor. The 300°C or the 250°C curves should be applied to Vitrohm units while the 375°C curve is applicable to open or unembedded resistors such as Ribflex.

If a resistor such as Vitrohm is rated on the basis of a 300°C rise and is subjected to 50 percent of rated load, the curve reveals that the temperature rise will be 195°C. Similarly, if a resistor rated on the basis of a 375°C rise has a temperature rise of 212°C, the curve indicates that the resistor is operating at 40 percent of rated load.

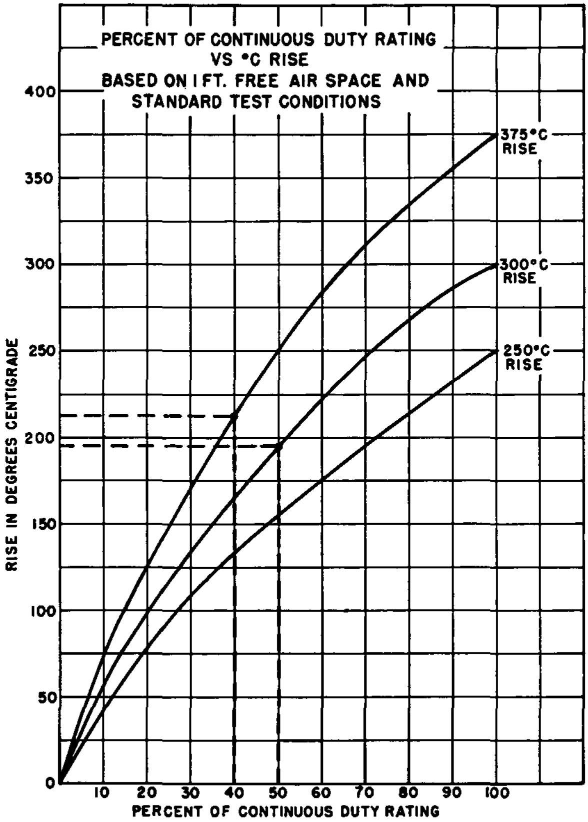


Figure 3-12. Percent of Continuous Duty Rating vs °C Rise

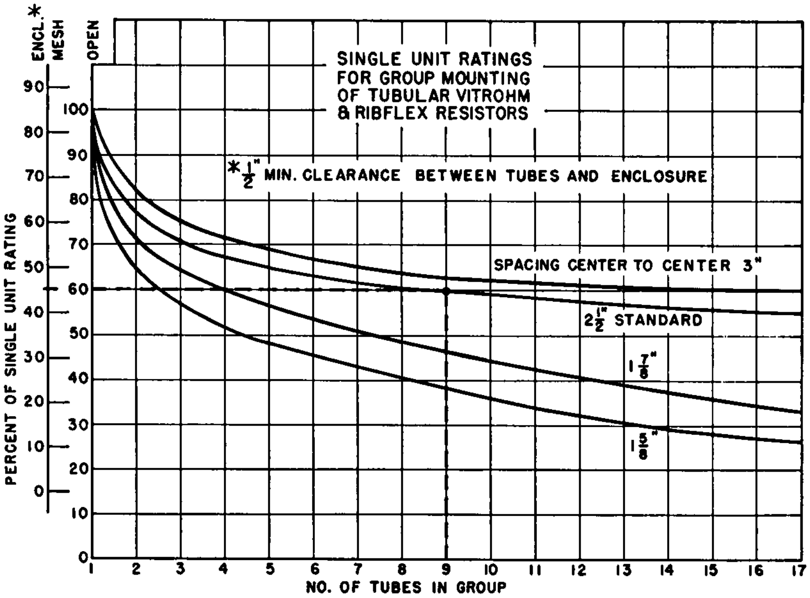


Figure 3-13. Single Unit Ratings for Group Mounting of Tubular Vitrohm and Ribflex Resistors.

b. Group Mounting—Figure 3-13 shows curves of percent of single unit rating against number of tubes in a group. Separate curves are given for four spacings, and in any group of three or more, the spacing between adjacent tubes is identical. Two percentage scales are shown; one for free air and the other for mesh enclosure. These curves apply to tubular Vitrohm and Ribflex resistors. Note that the rating varies with the spacing.

Example: With nine units in a group mounted in open air using 2½ inch centers, the percentage of single unit rating is 60 percent. Assuming each tube in the group is an 8½" D, rated at 160 watts continuous duty, then the continuous duty rating of the entire group is determined by:

Number of tubes in group x Rating of each tube x Percent of single-unit rating = Total continuous-duty rating of group.

$$9 \times 160 \times .60 = 864 \text{ watts}$$

c. Enclosures—Since resistors are seldom mounted in free space and still air, their nominal watt ratings must be reduced to avoid exceeding the maximum allowable temperature rise. For example, resistors are normally mounted either in separate enclosures or with other components tending to restrict ventilation and to cause an increase in temperature rise. In some instances, the temperature of associated components may bring the temperature of the resistor beyond safe limits. In other applications the reverse is true, i.e., other components may be damaged by the temperature of the resistor.

The approximate percentage derating for groups of Vitrohm resistors housed in metal mesh enclosures is shown in Figure 3-13. In the example given previously the total continuous duty rating of the group in free air is 864 watts. If this assembly of resistors is mounted in a metal mesh enclosure, the rating of the group must be reduced by 15 percent. The enclosed rating of the group is equal to 864 x .85 or 734 watts. The curves of Figure 3-14 compare the ratings of an 8½" D Vitrohm resistor when mounted in four different types of metal enclosures.

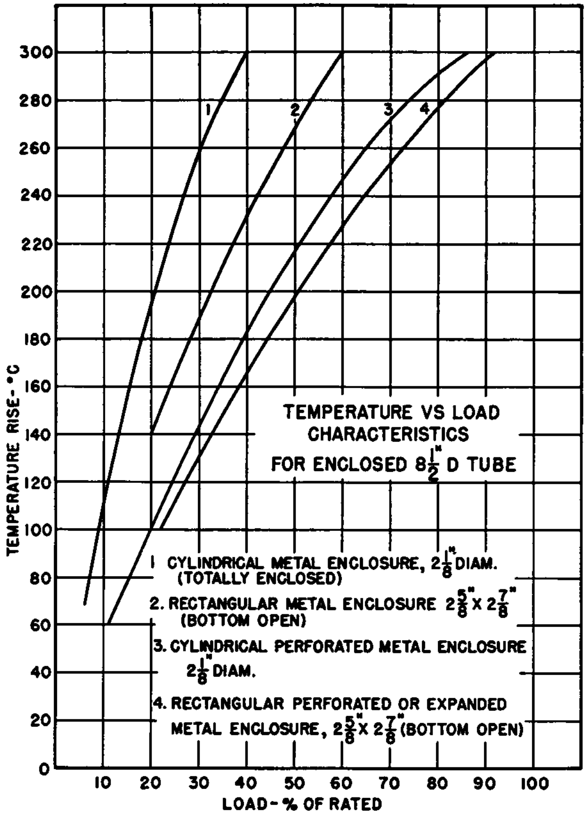


Figure 3-14. Temperature vs Load Characteristics For Enclosed 8½" D Tube

Figure 3-15. Adjustable tubular resistors, lower right, utilizing vertical through-bolt mounting are an essential component of the Electronic Automatic Alternator Voltage Regulator shown.

d. Maximum Voltage Limitations—Where high resistance values are required, the voltage impressed across the resistor terminals may take precedence over the resistor watt rating. On high-voltage circuits (600 volts or above), the voltage between turns of the winding must be kept within specified limits to assure safe operation and to prevent breakdown in service.

Table 3-3 Voltage Limitations

Core Length (in inches)	Maximum Recommended Voltage Rating	Core Length (in inches)	Maximum Recommended Voltage Rating
1	495	4½	2,230
1½	740	5	2,475
1⁹⁄₁₆	775	6	2,970
1¾	870	6⅛	3,150
2	990	6½	3,220
2⁵⁄₁₆	1,145	8	3,960
2½	1,240	8½	4,210
3	1,485	10	4,950
3½	1,735	10½	5,200
4	1,980	11¾	5,670
4¼	2,100	12	5,940

Table 3-3 lists the maximum recommended voltage rating expressed in RMS volts for Vitrohm tubular resistors of different core lengths. Ratings are based on a value of 495 RMS (700 peak) volts per linear inch of core length. The values shown will always assure safe operation devoid of failures. When high voltages are applied, Vitrohm resistors have withstood several times these values without impaired operation.

As an example of how to use Table 3-3, consider a type 50 F, 176,000-ohm, Vitrohm resistor which is rated at 50 watts and has a nominal core length of 4½ inches.

Computing the voltage across the tube required to dissipate 50 watts by the equation: $E = \sqrt{R \times W}$ where E is the voltage drop, R the resistance in ohms and W the watts dissipated we obtain 2970 volts. Table 3-3 shows that the maximum voltage rating for a $4\frac{1}{2}$ inch tube is 2230 volts. Thus, for safe operation, a 6 inch tube with a maximum voltage rating of 2970 volts should be selected.

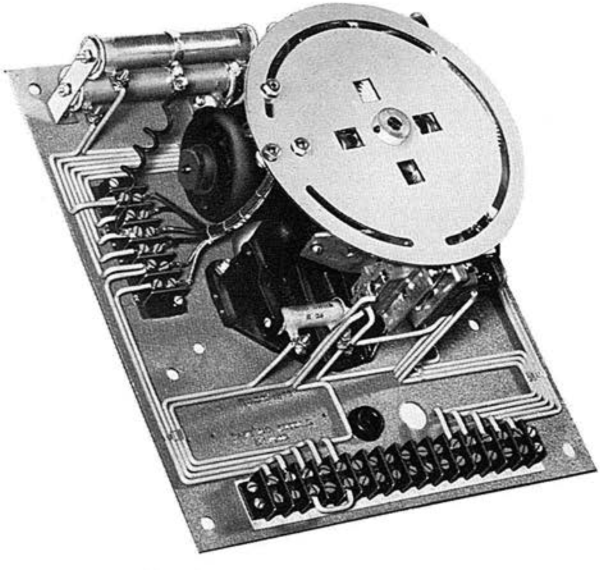


Figure 3-15.1. Vitrohm tubular resistors, at top of Rheostat Motor Drive Assembly, are for speed adjustment purposes.

In applications where extremely high-voltage surges for very short time intervals (milli-seconds) are known to occur surge-wound resistors are available. These resistors have wider spacings between the turns at each end of the tube, thereby increasing the insulation resistance between those turns.

e. Intermittent Duty — Vitrohm resistors are designed primarily for continuous-duty applications but there are numerous instances in which they are useful for intermittent-duty service. The curve of Figure 3-28 shows the high intermittent-duty ratings of Vitrohm tubular resistors. Under average conditions, the ratings indicated on the curve will not exceed the maximum permissible temperature rise of 300°C.

B. STRIPOHM RESISTORS.

Stripohm resistors, Figure 3-16, are especially useful in those applications where space for components is at a premium.

1. *Construction*—Except for the fact that Stripohm resistors utilize a flat, oval-shaped, ceramic base on which the resistive conductor is wound, they are practically identical in construction with Vitrohm tubular resistors. The core or base has a smooth surface with no sharp edges. This design precaution is taken to guard against wire breakage during manufacture. The fact that the core is slightly elliptical in shape, as indicated in Figure 3-16, increases the radiating surface slightly, provides a core considerably stronger than an ordinary flat rectangular base, and insures that the wire lies flat against the entire winding surface.

Stripohm resistors are equipped with metal strip (spring clip type) mounting brackets. Where adjustability is essential, Stripohms can be supplied with a bare side and band for adjustment of resistance value.

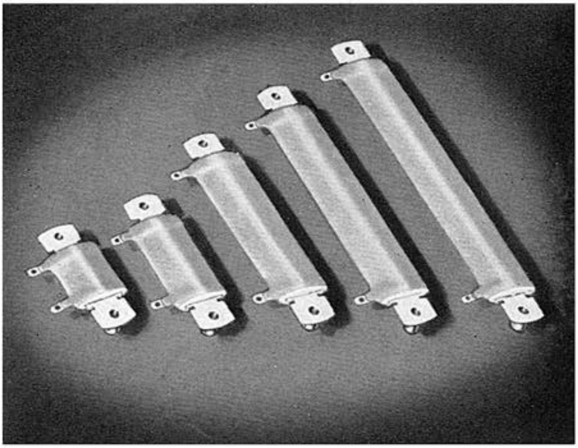


Figure 3-16. Stripohm Fixed Resistors equipped with spring-clip mounting brackets.

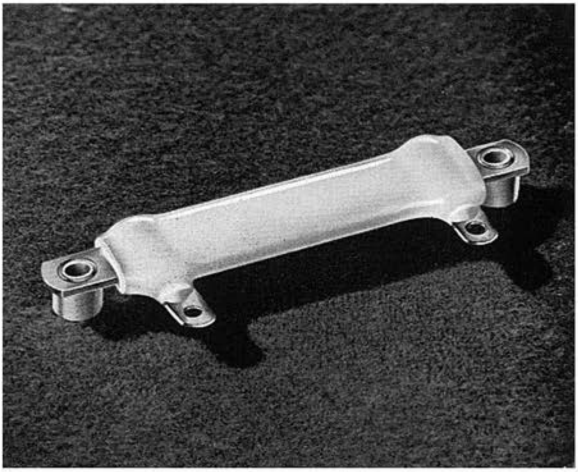


Figure 3-16a. 20 Watt Ministrip Resistor shown actual size.

Tapped Stripohm resistors, where more than one step is needed, are also available. On the largest size (6 inch) unit, twelve steps can be furnished. Tab terminals are standard for all Stripohms.

2. *Methods of Mounting*—Several methods of mounting Stripohm resistors are illustrated in Figure 3-17. In all methods the mounting brackets, as mentioned previously, are of the spring-clip type. Figure 3-17b is the standard mounting for single Stripohm resistors of all sizes. Figure 3-17c shows how Stripohms are stacked using standard brackets. To increase the stacked rating, $\frac{1}{16}$ inch metal spacers (washers) should be inserted between units. The method used in Figure 3-17a is for mounting single Stripohm resistors where the overall length of the assembly must be minimized. The method shown in Figure 3-17d, though unsuitable for stacked mounting, is useful where the overall height of a single Stripohm unit must be less than that found on standard brackets.

3. *Ratings*—Stripohm resistors are made in six standard sizes ranging from 20 to 75 watts. The method of rating strips is slightly different from that of conventional forms of resistors. A strip resistor is mounted horizontally on a vertical flat steel plate, 10 inches square and 0.040 inch thick, using the mounting brackets illustrated in Figure 3-17b. This entire assembly is then mounted in free air. The maximum permissible temperature rise on which the rating is based is 300°C in an ambient temperature not exceeding 40°C.

Resistance values range from a minimum possible resistance 0.1 ohm to a maximum possible resistance of 115,000 ohms. Resistance tolerance is the same as that for Vitrohm tubular resistors discussed on Page 47.

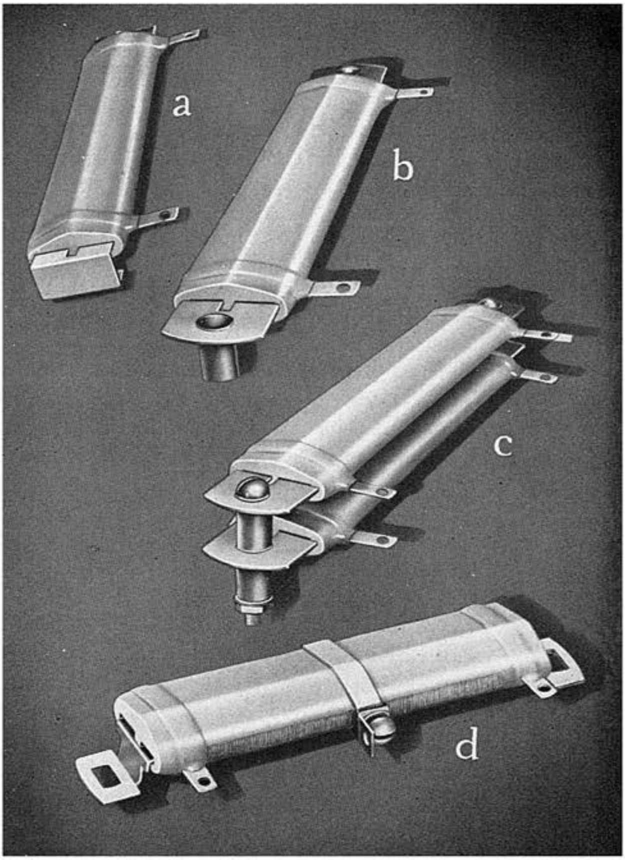


Figure 3-17. Typical Methods of Mounting Stripohm Resistors
a—Inverted metal spring clip, b—Standard metal spring clip, c—Stack mounting using standard brackets, d—Metal spring clip.

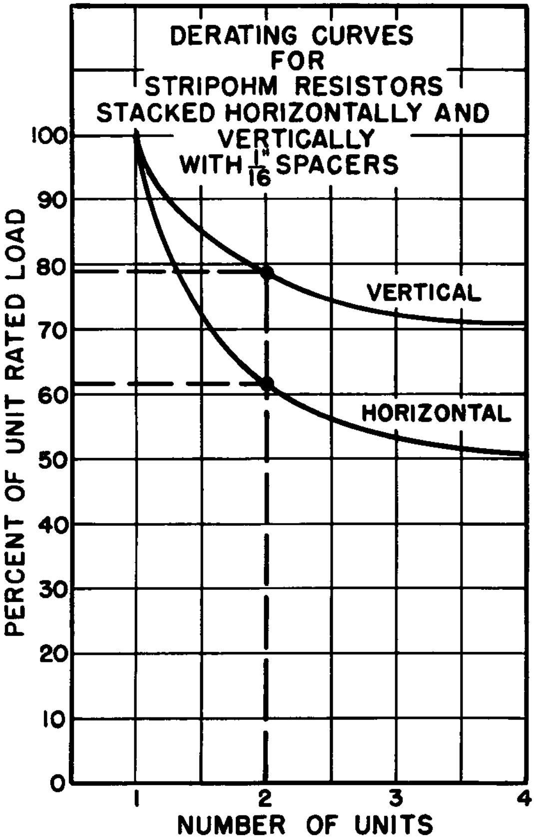


Figure 3-18. Derating Curves for Stripohm Resistors stacked horizontally and vertically

4. *Performance Data*—Except for slightly lower resistance to high mechanical shock, Stripohm resistors can meet the same tests as outlined for Vitrohm tubular resistors. The shorter length units should be specified where vibration is excessive and multi-stacked assemblies should be avoided where severe mechanical shock conditions prevail. Salt water immersion tests (Page 56) on Stripohm resistors are based on a maximum allowable temperature rise of 175°C.

5. *Application Data* — Because Stripohm resistors utilize Vitrohm construction, the application data given on pages 59 to 67 for Vitrohm resistors, except for grouping and spacing information, can be applied to Stripohm units.

a. Group Ratings—Figure 3-18 shows the effect of stacking on the rating of Stripohm resistors. All resistors are equipped with standard spring clip brackets as shown in Figure 3-17b. For example, 55-watt Stripohm resistors, stacked in groups of two with their faces vertical, are rated at 79% of 55, or 43.4 watts. If stacked with their faces horizontal, the rating is 61.5% of 55, or 33.8 watts.

C. VITROHM NON-INDUCTIVE RESISTORS.

Vitrohm fixed resistors of the non-inductive type, Figure 3-19, are designed for high-frequency circuits when power up to 160 watts per unit must be dissipated.

1. *Construction*—The basic difference in construction between standard and non-inductive Vitrohm tubular resistors is in the method of winding the resistive conductor. In order to lower substantially the inductance and minimize distributed capacitance, non-inductive Vitrohm resistors utilize the Ayrton-Perry method of winding.

The Ayrton-Perry winding consists of two windings in parallel, wound in a single layer in opposite directions.

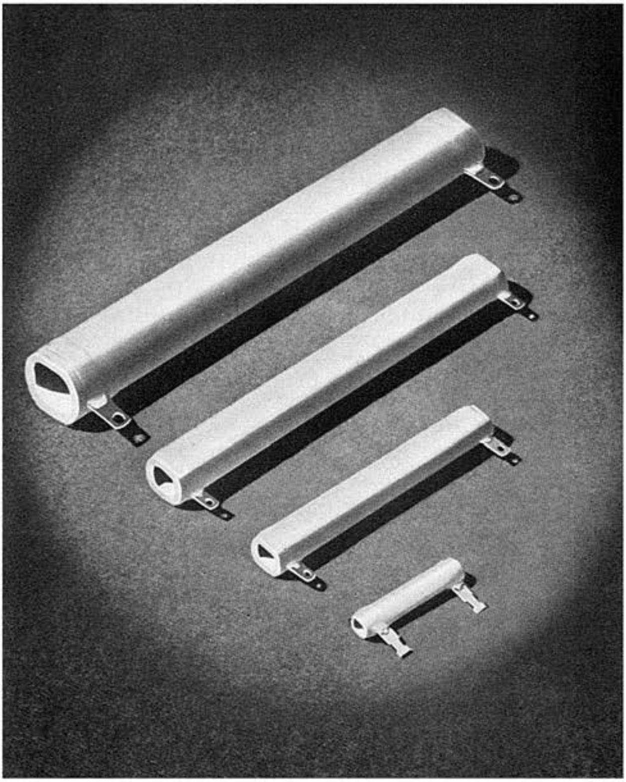


Figure 3-19. Vitrohm Non-Inductive Tubular Resistors

The turns of the windings cross at fixed points that are at the same potential. In order to insure that the points at which the windings cross are exactly 180° apart, the cylindrical-shaped ceramic core is made with two flat surfaces. This patented method of flat-sided construction further reduces the amount of undesirable inductance. It is vastly superior to the conventional cylindrical non-inductive resistor without flatted sides.

2. *Terminals* — Vitrohm non-inductive resistors are made with tab or ferrule type terminals illustrated on Page 40.

3. *Mountings*—Push-in type mounting brackets are recommended for units equipped with tab terminals. Ferrule type non-inductive resistors require fuse clips for mounting purposes.

4. *Ratings* — D.C. wattages of non-inductive tubes range from 10 to 160 watts in 5 standard sizes. Resistance values are available from 1 to 15,000 ohms. Because of the method of winding used, the maximum resistance obtainable per unit is lower than with standard Vitrohm resistors.

5. *Performance Data*—Vitrohm non-inductive resistors can successfully withstand the same performance tests as standard Vitrohm units. See pages 48 to 59 for further details.

6. *Application Data*—These data, given for Vitrohm tubular resistors on Pages 59 to 67, apply equally well to Vitrohm non-inductive resistors.

7. *Effects of Frequency*—The distributed inductance and capacitance of a wire-wound resistor become increasingly important as the frequency rises. Wire size, core size, manner of winding, spacing, etc., all affect the distributed inductance and capacitance.

The curves in Figure 3-20 were made from experimental data taken on several 8½″ D, Vitrohm, non-inductive resistors, and may be considered representative. In these tests, total reactance was measured and since the capacitive reactance is smaller than the inductive reactance, the total reactance as shown on the curves is inductive.

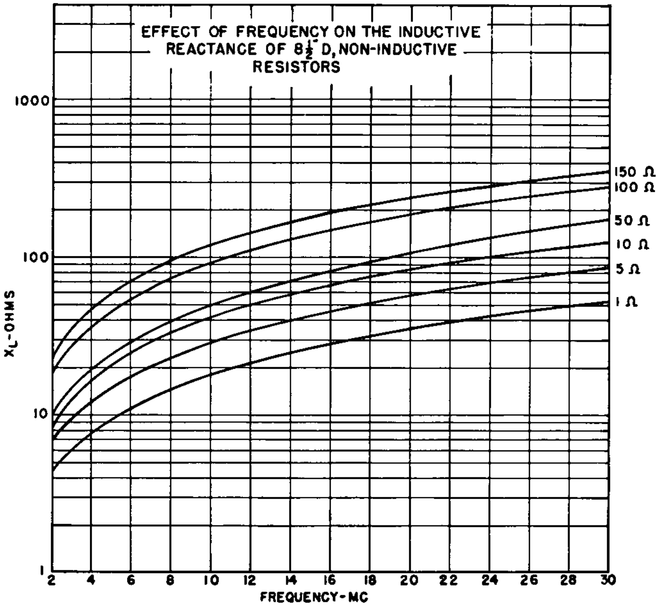


Figure 3-20. Effect of Frequency on the Inductive Reactance of 8½″ D, Non-inductive Resistors

The equation for inductive reactance is:

$$X_L = \omega L = 2\pi fL$$

Where f is the frequency and L the inductance.

The equation for capacitive reactance is:

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi fC}$$

Where C is the capacitance. The total reactance is the algebraic sum of X_L and X_C.

The schematic diagram of a resistor in a high-frequency circuit is shown in Figure 3-21, where R is the effective resistance, L the distributed inductance, and C the distributed capacitance. The effective resistance is greater than the D.C. resistance due to the high-frequency A.C. "skin effect" in the resistive conductor. The impedance of the resistor is then equal to the vectorial sum of the effective resistance and the reactance.

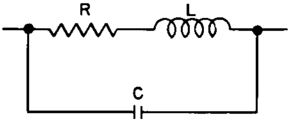


Figure 3-21. Schematic Diagram of a Resistor in a High-frequency Circuit

D. PLAQOHM RESISTORS.

Vitrohm Plaqohm Resistors, Figure 3-22, are another popular form of non-inductive resistor, suitable for numerous applications in radio and electronic circuits where a combination of power and high frequencies exists. These flat-type resistors are particularly useful in equipment where space for components is extremely limited.

1. *Construction*—As shown in Figure 3-22, the plaques in which the resistance wire or ribbon is placed are made of molded refractory ceramics, rectangular in shape. One side of the base contains molded slots for holding the resistive conductor in place and for providing proper spacing and insulation between turns. Copper terminals are silver brazed to the ends of the resistive conductor. The entire assembly, that is, the base, winding and terminal joints, is then coated with a fused-on vitreous enamel. The complete assembly forms a solid homogeneous mass, without air pockets, to provide for the rapid conduction of heat from the resistive conductor to the surfaces of both sides of the resistor.

All Plaqohm resistors use the bifilar method of winding to give low values of inductance. This method is quite different from that used on Vitrohm tubular non-inductive resistors. Instead of being wound around the base, the winding is flat and zigzags in the slots in the base. Since each segment of the winding is adjacent to another segment in which the current flows in the opposite direction, the flux linkages cancel, reducing the total inductance. In addition, because there is small potential difference between alternate adjacent ends of the segments and the distance between each segment is relatively large, the distributed capacitance is held to a minimum.

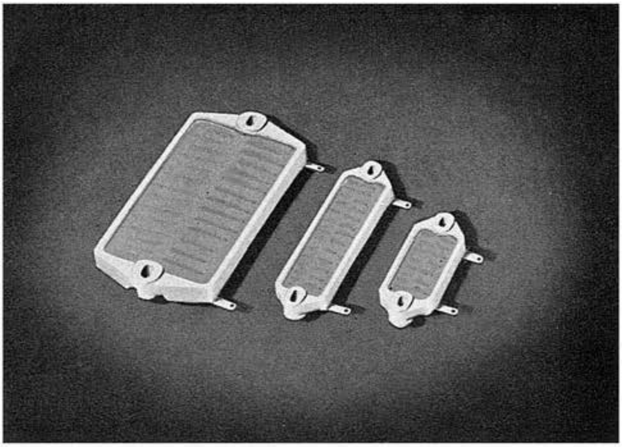
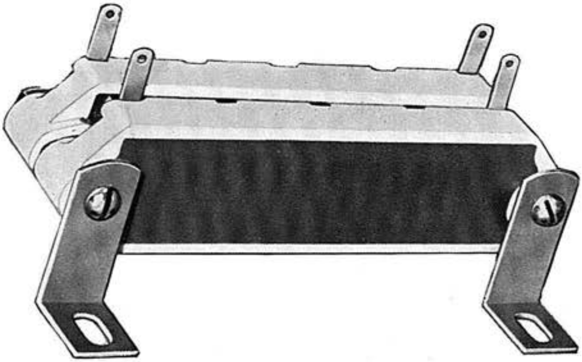


Figure 3-22. Plaqohm Non-Inductive Resistors

Standard Plaqohm resistors are made with two tab terminals. On the smallest size Plaqohm an additional slot is provided in each base for a third terminal when required. Larger size Plaqohms can be supplied with three extra terminals for applications where four resistance steps are required in a single Plaqohm.

2. *Mountings* — Typical methods of mounting these resistors are illustrated in Figure 3-23. When two Plaqohms are stacked Figure 3-23a, they should face in the same direction and not be placed back to back. This precaution should be observed to allow sufficient electrical clearance between terminals of adjacent units. Where more than two resistors are stacked, four L-shaped mounting brackets should be used for proper support.



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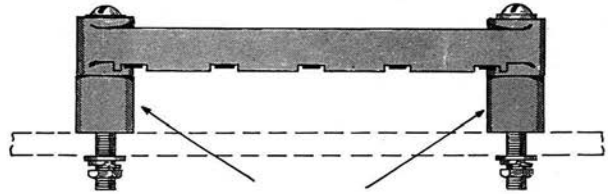
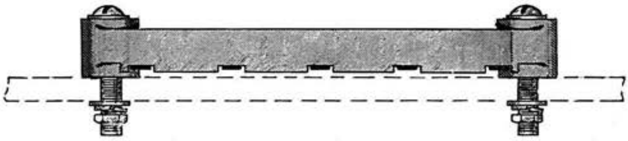


b

Mounted on steel panel using metal or ceramic spacers



c

Mounted on heat resistant insulating panel

Figure 3-23. Methods of Mounting Plaqohm Resistors

a—Vertical L-shaped bracket mounting, b—Horizontal mounting with spacers, c—Horizontal contact mounting

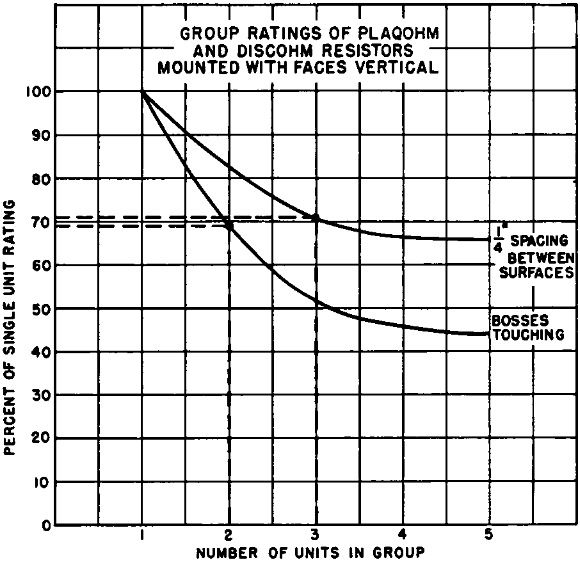


Figure 3-24. Group Ratings of Plaqohm Resistors and Discohm Resistors mounted with their faces vertical

When vertical space for components is limited, mountings shown in Figure 3-23b and c may be used. If two or more Plaqohms are to be grouped, horizontal mounting is not recommended. When mounting the resistors on a metal surface (steel panel) as in Figure 3-23b, the vitreous enamel side of the plaque should face away from the mounting panel surface. Spacers must be used to provide adequate clearance between resistor terminals and the panel. Contact mounting, shown in Figure 3-23c, should be used only when the mounting panel is made of an insulating, heat resistant material.

3. *Ratings* — Plaqohm resistors are made in three standard sizes, rated at 25, 50 and 150 watts. Individual ratings are based on a maximum temperature rise of 300°C in free air. Resistance values range from 0.5 ohm minimum to 86,400 ohms maximum.

4. *Performance Data*—The test results given previously for Vitrohm tubular resistors apply, in general, to Plaqohm resistors. The molded ceramic base employed is not quite as strong as the extruded tubular ceramic cores found in Vitrohm tubular units. For this reason the large size Plaqohms, or multi-stacked assemblies, are usually not recommended. Where severe vibration or high mechanical shock is encountered, the shorter length units can be used satisfactorily.

5. *Application Data* — For load versus temperature rise characteristics and derating factors for enclosures, the data given for Vitrohm tubular resistors, Page 59 can be used.

a. A.C. Characteristics—Because of the method of winding, the inductance at frequencies up to 5 megacycles is negligible. Plaqohms are essentially free from standing waves at all frequencies up to 60 megacycles.

A single Plaqohm mounted four inches away from any object and not in the magnetic or electrostatic field of other devices, maintains its resistance value without major variations resulting from frequency changes. This condition prevails at frequencies up to 7, 3 and 0.2 megacycles for the 25, 50 and 150 watt units respectively.

b. Group Ratings—Curves of Figure 3-24 may be used to determine free-air ratings for groups of Plaqohm resistors mounted vertically. For example, three 50-watt Plaqohm resistors with ¼ inch spacing between adjacent surfaces will have their rating reduced approximately 29 percent, or to 3 x 50 x .71 = 106.5 watts. If two 150-watt Plaqohm resistors are touching each other, that is, mounted side by side without spacing, the rating is reduced 31 percent, or to 2 x 150 x .69 = 207 watts.

When the resistors are stacked with their faces horizontal, the group ratings given in the above examples should be further decreased by 10 percent. Other reductions are necessary when individual or groups of Plaqohms are enclosed.

E. DISCOHM RESISTORS.

Another type of non-inductive resistor, known as Discohm, Figure 3-25, is recommended for low-power applications where panel space must be conserved.

1. *Construction*—Discohm resistor construction follows very closely that of the Plaqohm resistors, Page 77, except that the winding is laid out radially. The terminals are silver brazed to the resistive conductor and the entire assembly is protected by Vitrohm enamel. Unlike Plaqohm units, Discohm resistors are unavailable with extra taps for additional steps.

2. *Methods of Mounting*—Discohm resistors are normally mounted by means of metal bolts passing through the countersunk hole in the molded refractory ceramic base as shown in Figure 3-26a. L-shaped brackets Figure 3-26b are sometimes used for mounting 1, 2 or 3 units. The method used in Figure 3-26c combines a through-bolt with two L-shaped metal brackets. The metal spacers are used to increase the single-unit watt rating.

3. *Ratings*—The free-air rating of Discohms based on a 300°C rise is 24 watts. For higher power applications, two or more Discohms must be stacked together. The use of multiple-stacked assemblies is often advantageous where multi-tapped or multi-section units are needed. Resistance values range from 1 to 5760 ohms per disc.

The curve given in Figure 3-24 for Plaqohm resistors can be used as a guide for derating groups of Discohms since their characteristics are similar. Refer to Page 81 for application and performance data.

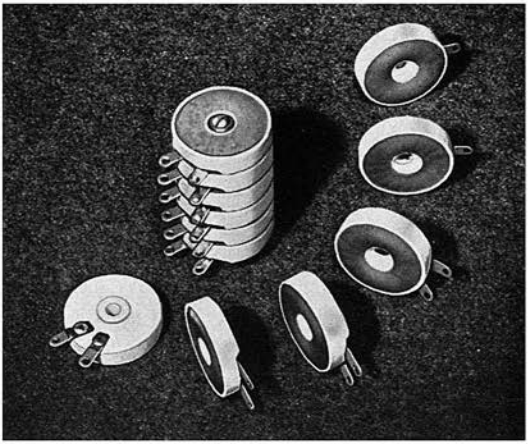


Figure 3-25. Discohm Resistors

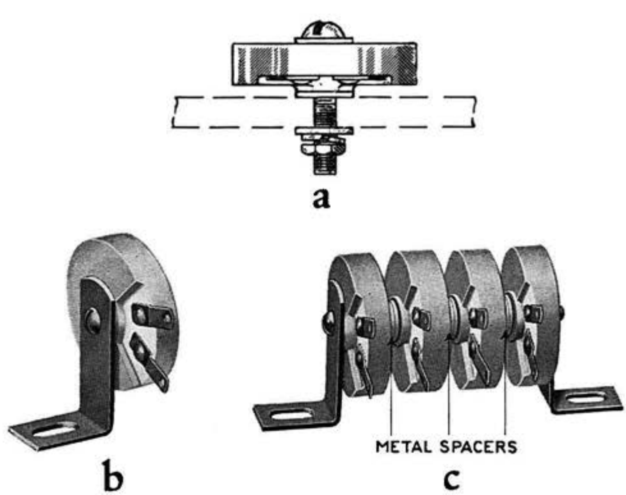


Figure 3-26. Methods of Mounting Discohm Resistors
a—Flush mounting, b—L-Shaped brackets, c—Through-bolt with L-Shaped brackets.

F. RIBFLEX RESISTORS.

Ribflex ribbon-wound resistors are designed for intermittent-duty applications, where high wattages must be dissipated by relatively small size resistors, and for continuous-duty resistors, where low resistance values are needed.

1. *Construction*—Ribflex resistors, Figure 3-27, consist essentially of crimped resistance ribbon wound on edge on a refractory ceramic tube, and silver brazed at each end to heavy, screw-type terminals. Vitreous enamel is applied to the surface to anchor the ribbon and terminals securely in place.

Ribflex construction offers several advantages over conventional forms of tubular flat-wound, ribbon resistors. First, the crimped ribbon affords a greater surface area for heat dissipation compared with units using flat-wound ribbon or wire. Second, because Ribflex resistors are classified as bare resistors, the maximum permissible temperature rise is 375°C. The increased temperature rise gives higher wattages for a given size. Third, since the resistance ribbon and terminals are permanently secured to the ceramic tube, Ribflex units are more adaptable than bare-type resistors to applications where mechanical shock and vibration are encountered.

2. *Terminals*—Heavy-weight, screw-type terminals are considered standard for Ribflex resistors. For applications where two or more steps are required per tube, terminal taps can be provided. The maximum allowable number of taps per tube depends on the nominal length of the resistor and on the resistance required per step. Adjustable band-type terminals, similar to those used on Adjustohm resistors, can be used where adjustability is needed.

3. *Mountings* — All the methods of mounting described on Page 42 for Vitrohm fixed resistors are

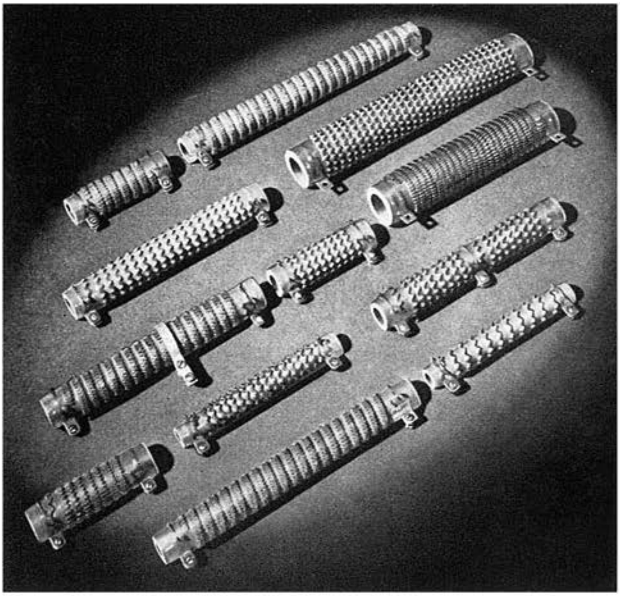


Figure 3-27. Ribflex Resistors

applicable to Ribflex units. Through-bolt type mounting brackets are recommended for mounting two or more Ribflex resistors.

4. *Ratings*—Continuous duty ratings for Ribflex resistors range from 75 to 600 watts maximum. Standard resistance values are from 0.04 ohm minimum to 66 ohms maximum, per tube.

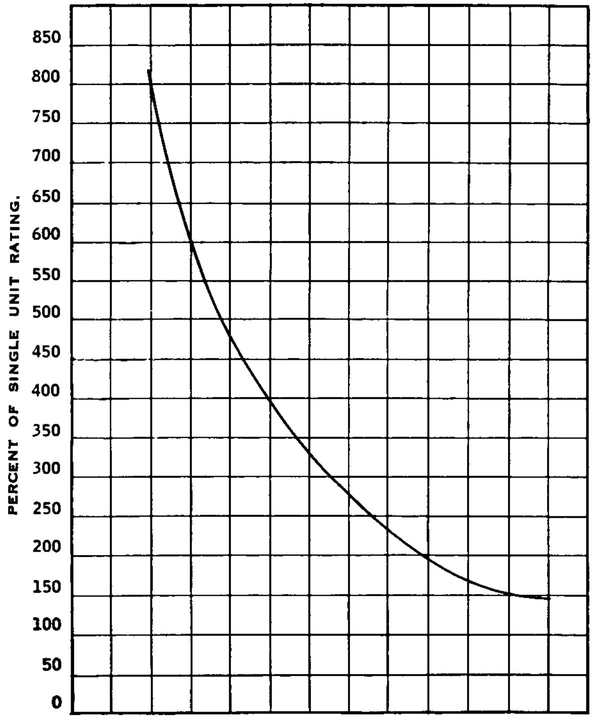
The standard resistance tolerance for Ribflex units from 0.5 to 66 ohms is ± 10%. For values below 0.5 ohm and on tapped units the tolerance is ± 15%. Ribflex resistors with tolerances as low as ½ of 1 percent are available at increased cost.

5. *Performance Data*—Although Ribflex resistors are classified as open- or bare-type resistors, they successfully meet many of the tests described on Pages 48 to 59 for Vitrohm tubular resistors. For example, Ribflex units withstand the same momentary overload, mechanical strength, mechanical shock and thermal shock tests performed on Vitrohm units. The heating and cooling curves for Ribflex are also similar to those given on Pages 50 and 51. Because the resistive element is exposed, "wet" tests such as salt spray, humidity and salt immersion are not as favorable as for embedded types. In the case of the salt spray immersion, for example, the number of hours Ribflex units withstand this test depends mainly on the resistance alloy used. However, specially designed Ribflex units have been manufactured specifically for marine service.

6. *Application Data*—When using Ribflex resistors, data given for Vitrohm tubular resistors, including load versus temperature rise, grouping and spacing, and derating for enclosures are applicable.

7. *Intermittent-duty Ratings* — Intermittent-duty ratings for Ribflex and other resistors are based on their continuous-duty rating and then modified according to the duty cycle. The curve in Figure 3-28 gives the relationship between the percent of single unit watt ratings of resistors at various intermittent duty cycles. The values shown are with 2½ inch spacings and a maximum temperature rise of 375°C.

To apply this curve, let us assume that in a motor starter for a D.C. motor driving a constant speed compressor, the duty cycle is to be 10 seconds "on" out of each 80 seconds and that the power to be dissipated in starting is 13,000 watts (RMS). From Figure 3-28 it can be seen that the rating for the specified duty cycle is 475 percent or 4.75 times the continuous duty rating.



Seconds on	5	10	15	15	15	15
Out of each	80	80	90	60	45	30

Figure 3-28. Effect of Intermittent-duty Operation on Rated Capacity of Vitrohm and Ribflex Resistors

Referring to Table 3-4, we find that twelve 11¾" D tubes will be required if the resistor assembly is mounted in free air. Table 3-4 compensates only for derating the tubes when grouped, using 2½ inch centers. For mounting on 1⅝", 1⅞" or 3" centers use curve Figure 3-13—page 61.

Table 3-4 Continuous-Duty Ratings of Grouped Ribflex Resistors*

Mounted on 2½" centers

Size Tube	NUMBER OF RESISTORS IN GROUP								
	1	2	3	4	6	9	12	17	22
4¼" D	155	235	330	415	590	835	1090	1440	1770
6½" D	240	365	510	645	910	1300	1680	2230	2640
8½" D	300	460	640	805	1140	1620	2110	2780	3300
10½" D	375	575	800	1010	1420	2020	2640	3480	4130
11¾" D	420	640	895	1130	1595	2270	2950	3880	4620

*Assembled group suspended in still air at least one foot from nearest object.

In practice, further derating is required to compensate for increased temperature rise when the tubes are mounted in an enclosure or in locations where ventilation is restricted. This ordinarily means increasing the size or number of tubes in the group. No specific calculations can be given that will apply to all applications since conditions vary so widely. However, the safest procedure is first to estimate the rating of the group based on the above example. Then add sufficient units to the group to compensate for lack of ventilation, other spacings, etc. Finally, run temperature rise tests under conditions simulating those in the actual application.

G. EDGEOHM RESISTORS.

Industrial demands for high-current resistors, lighter in weight and sturdier in construction than cast iron grid resistors, prompted development of Edgeohm re-

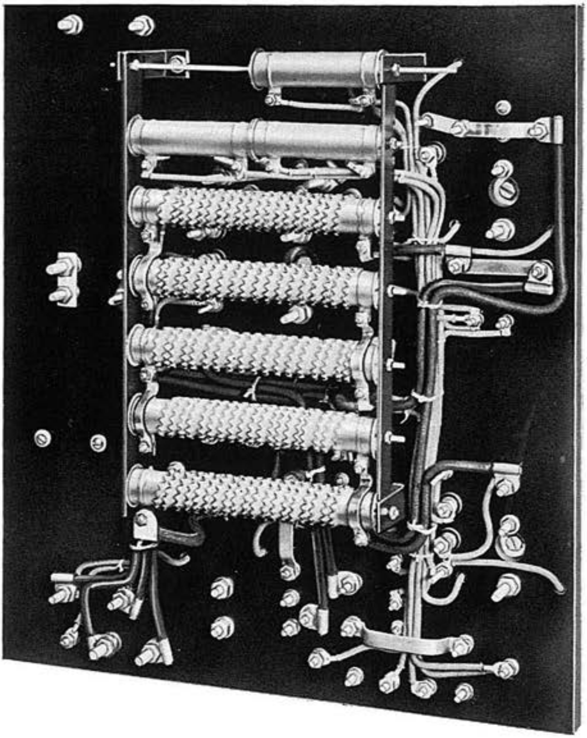


Figure 3-29. Rear view of D.C. motor starter. Ribflex resistors, lower section, are for starting purposes. Vitrohm tubular resistors, upper section, are for control circuit purposes.

sistors. Another vital factor influencing the original design was the need for high-current resistors that could be used economically in both intermittent- and continuous-duty applications.

1. *Construction* — A typical Edgeohm high-current resistor is shown in Figure 3-30. The resistive conductor consists of a single piece of non-corrosive resistance ribbon wound on edge to form oval-shaped coils. This continuous ribbon element is mounted on grooved ceramic saddles that space adjacent turns and insulate the resistive conductor from the supporting metal bars. End pieces of steel are utilized to space the supporting bars. For external connection to each end of the resistive conductor clamp-type terminals are provided. Where taps are required along the resistive conductor additional clamp-type terminals are readily attached.

2. *Mountings*—There are two standard methods of mounting Edgeohm resistors. For single units stamped steel mounting brackets, Figure 3-31a, are recommended. These brackets assure maximum cooling and convection efficiency since the resistor is mounted with the long axes of the unit and the oval coils in the same horizontal plane. Stamped steel brackets are equally suited for mounting on metal or insulated panels.

The second standard method of mounting Edgeohm resistors is by means of steel mounting frames shown in Figure 3-31b and c. These frames accommodate from one to three units in a single frame and may be stacked in one or more vertical tiers.

In both types of mounting, secondary insulation is provided between the resistor assembly and the steel mounting brackets. This additional precaution affords double insulation between the ribbon element and ground, primary insulation being furnished by the ceramic saddles of the Edgeohm resistor.

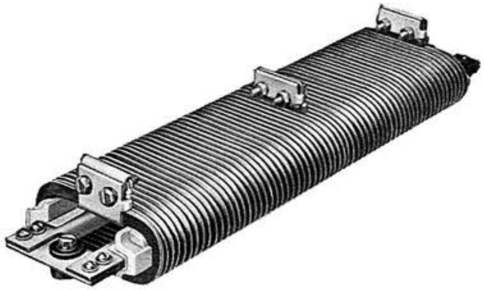
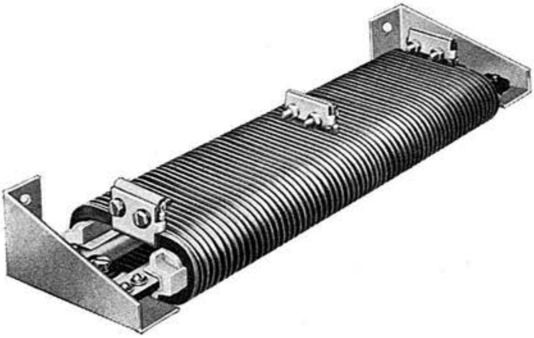


Figure 3-30. Edgeohm Resistor without Mounting Frames or Brackets

3. *Ratings*—Because Edgeohm resistors utilize unembedded or bare resistive elements, free-air rating for a single unit is based on a maximum temperature rise of 375°C. Edgeohm resistors are made in five standard lengths, 5⅞ inches to 19 inches maximum. The continuous-duty rating of the 19 inch Edgeohm resistor is 2,200 watts.

Variations in resistance and current capacity are obtained by changes in alloy, size (cross-sectional area) and length of the ribbon. The standard range of resistance values is from 0.05 to 4.40 ohms, while the continuous current rating is from 79 to 21 amperes. Resistance tolerance on all units is + 20 — 10%.

4. *Performance Data*—Edgeohm resistors, like Ribflex tubular units, meet many of the tests that are made on embedded power resistors. When equipped with suitable mountings, Edgehom units, singly or in multi-deck assemblies, withstand an exceptionally high degree of mechanical shock. Standard units meet the requirements for railway and other mobile equipments. Edgeohm resistors, after being subjected to more than 100 hours in the salt spray corrosion test, show no visible damage from the effects of corrosion and, electrically, no measurable change in resistance values occurs.



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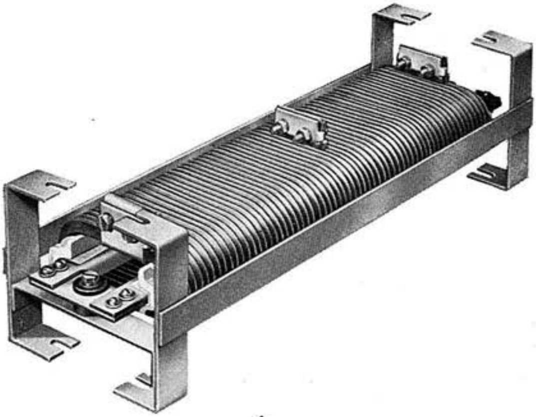
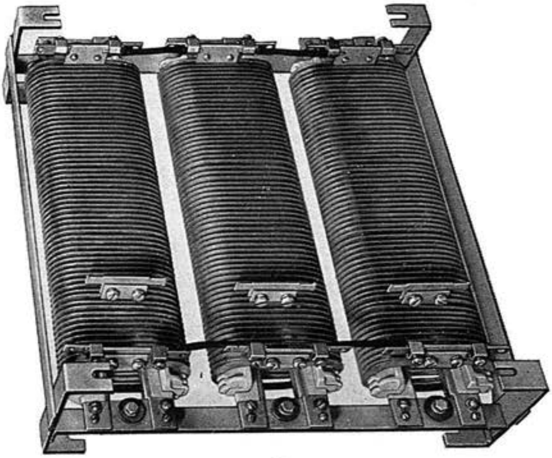


b

Figure 3-31a. Typical Methods of Mounting Edgeohm Resistors
a—Stamped steel brackets—single unit mounting, b—Steel mounting frames.



c

Figure 3-31b. Typical Methods of Mounting Edgeohm Resistors
c—Multi-unit mounting using steel mounting frames.

5. *Application Data*—The same general precautions as already described for Ribflex resistors should be taken when applying Edgeohm resistors. Reductions in free-air ratings should be made for grouping two or more units, enclosures, etc.

6. *Intermittent-duty Ratings*—The effect of intermittent-duty operation on the ratings of an Edgeohm resistor are shown in Figure 3-32. Ratings given are based on a 375°C rise in free air.

If 8,800 watts (RMS) must be dissipated during a duty cycle of 10 seconds "on" out of each 80 seconds, Figure 3-32 indicates that the percent of continuous

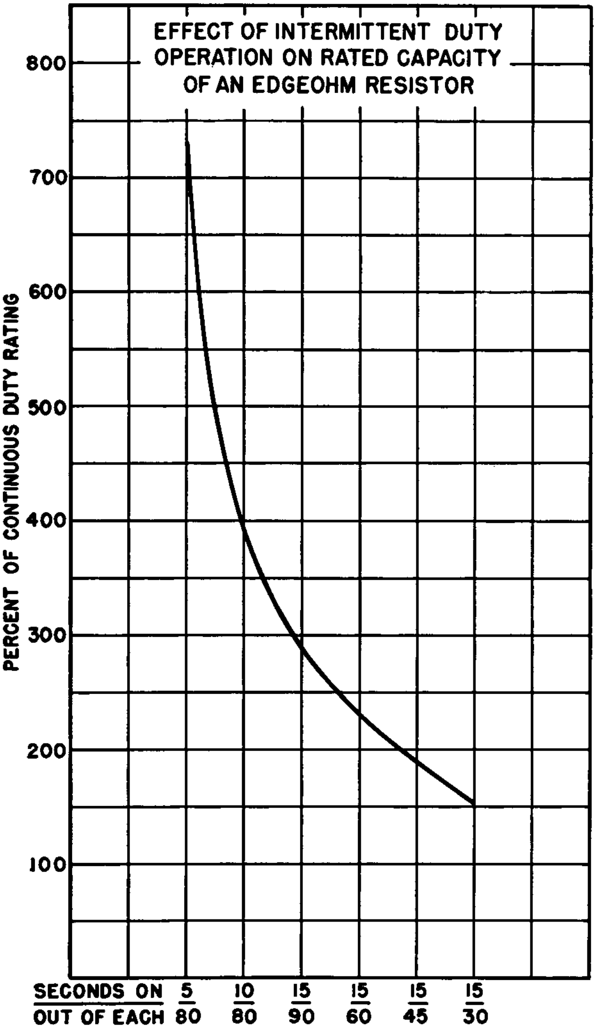


Figure 3-32. Edgeohm Resistor Intermittent-duty Ratings.

duty rating is approximately 400 percent, or 4 times the continuous-duty rating. Selecting Edgeohm resistors rated at 2,200 watts continuous duty, we note that one resistor will be needed, as determined by the following equation:

$$\text{Number of resistors required} = \frac{\text{Intermittent-duty watts (RMS)}}{\text{Continuous-duty rating} \times \text{Per cent of continuous-duty rating}}$$

$$\text{Number of resistors required} = \frac{8{,}800}{2{,}200 \times 4} = 1$$

7. *Group Ratings*—Table 3-5 can be used as a guide in determining the continuous-duty ratings of Edgeohm resistors when group mounted. In horizontal stacking the long axes of the unit and of the ribbon coil are horizontal. The vertical centerline-to-centerline dimension is 5 inches and units are mounted one above the other. In vertical stacking the long axis of the coil is vertical and units are mounted one above the other with 6½ inch centerline-to-centerline spacing.

Table 3-5 Group Ratings of Edgeohm Resistors

Method of Stacking	PERCENT OF SINGLE UNIT RATING*		
	One Unit	2 Tiers High	3 Tiers High
Horizontal	100	90	80
Vertical	70	60	—

*Continuous-duty ratings based on a maximum temperature rise of 375°C in 40°C ambient air. Units are mounted in free air.

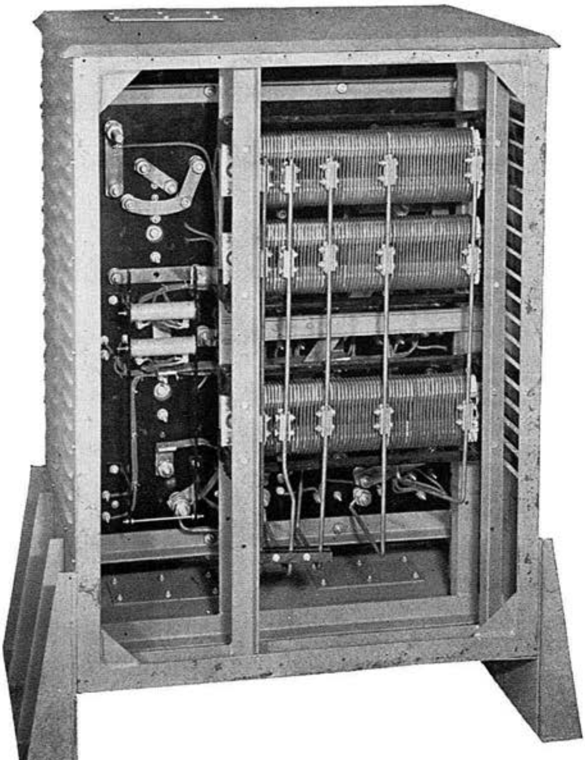


Figure 3-33. Rear view of D.C. motor controller. The Edgeohm starting resistors, at right, are mounted with long axis of coil vertical to conserve space.

Figure 3-34. Typical Barohm Resistor

H. BAROHM RESISTORS.

Barohm resistors are designed for high-current applications requiring a low-cost, light-weight, continuous-duty resistor.

1. *Construction*—A Barohm resistor, as illustrated in Figure 3-34, consists of a channel-shaped alloy resistance ribbon, of uniform cross section, formed in a series of flat turns secured at the middle of their short axes to specially treated asbestos cement composition support bar. The ends of the support bar are provided with mounting holes. External connections to the resistive conductor are made by means of two stud-type terminals, Figure 3-35b. Additional taps on the resistive elements can be furnished on the support board, or clamp-type terminals can be supplied for connection along the ribbon.

Although the support bars are made in lengths from 6 to 30 inches, the 23 inch length is considered standard. To meet varying height requirements, standard heights of 16, 20 and 24 inches are available.

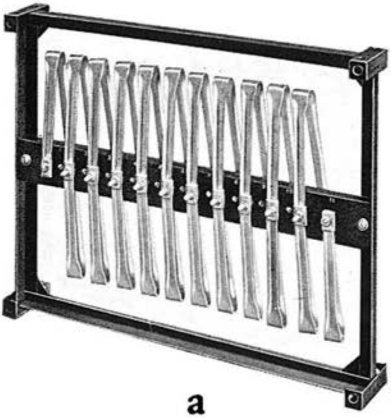
2. *Mountings*—Barohm resistors may be mounted in open, or enclosed, formed steel frames as shown in Figure 3-35a and b. Notice that the long axis of the ribbon is vertical. Enclosed frames are suitable for floor mounting while the open-type frames are suitable for mounting directly on panels or switchboards. The open-type frame is useful for applications requiring multi-unit assemblies. For the larger resistance banks, it is common practice to mount individual units in a specially built angle iron frame either open or enclosed, with perforated or expanded metal mesh instead of solid, sheet steel panels. The metal mesh protective enclosure is preferred because it allows adequate ventilation.

3. *Ratings*—The continuous-duty ratings of Barohm resistors are based on a 375°C temperature rise for a single unit mounted in free air with the long axis of the resistive ribbon vertical. Continuous-duty current capacities range from 340 amperes maximum to 18 amperes minimum.

Resistance values are obtainable from 0.15 to 7 ohms maximum on standard units. Factors that determine resistance limitations include: length of ribbon that can be placed in the allotted space, size of ribbon used and resistance alloy selected. Standard resistance tolerance is $+20\ -10\%$.

4. *Performance Data*—Barohm resistors are generally unsuited for application where high mechanical shock, humidity or salt spray is encountered. The impregnated asbestos support for the alloy resistance ribbon is considerably weaker mechanically than the ceramic saddle, steel support base utilized on Edgeohm resistors. However, for ordinary commercial and industrial applications Barohm units prove entirely satisfactory and, in general, are the most economical form of high-current resistor for continuous-duty service.

5. *Application Data*—The curve in Figure 3-36 illustrates the effect of load versus temperature rise on Bar-



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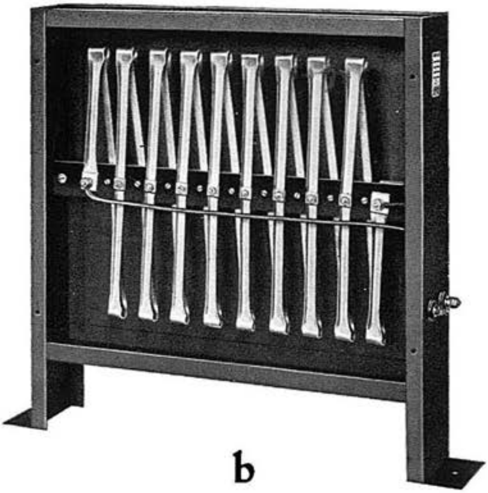


b

Figure 3-35. Typical Methods of Mounting Barohm Resistors
a—Open type metal frame, b—Enclosed frame for floor mounting—front cover removed.

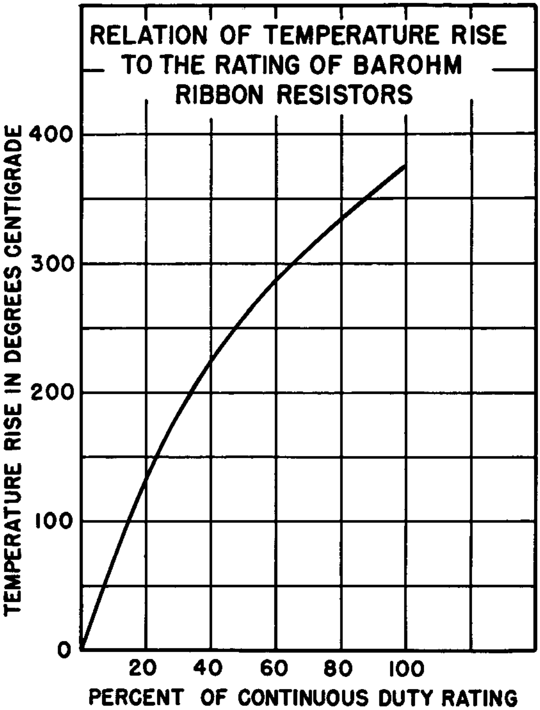


Figure 3-36. Percent of Continuous-duty Rating versus Temperature Rise of Barohm Resistors

ohm resistors. Ratings given represent average values of typical size units mounted in open-type frames like the one in Figure 3-35a. Where two or three units, each mounted in open-type frames, are stacked side by side, the nominal rating of each unit should be reduced by about 10 percent. On multi-unit assemblies containing four or more Barohms, each mounted on open-type frames, the nominal rating of each unit should be reduced by 15 percent. Further reductions in these free-air ratings must be made for operation in ambients higher than 40°C, in enclosures, etc.

To illustrate the use of the curve shown in Figure 3-36, assume a single Barohm resistor, rated at 100 amperes and having a resistance of 0.31 ohms, carries a load of 50 amperes. The temperature rise of the resistor can be estimated as follows:

$$\text{Watts dissipated} = I^2R = 50^2 \times 0.31 = 775 \text{ watts}$$

$$\text{Percent of continuous duty watts} = \frac{775}{3100} = 25\%$$

Referring to the curve in Figure 3-36, the 25 percent of continuous duty rating will give a temperature rise of approximately 150°C.

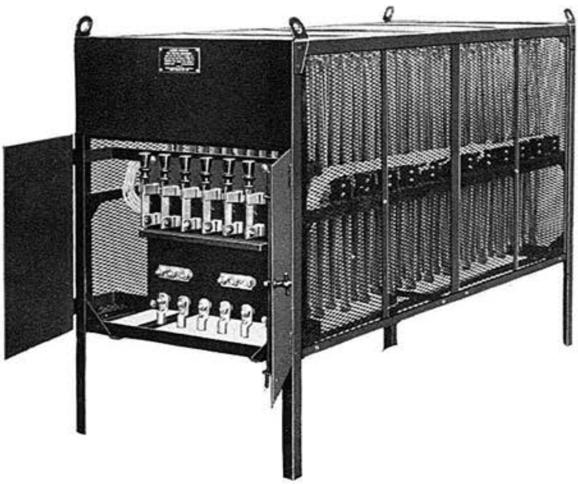


Figure 3-37. The 100 K.W. Loading Rheostat illustrated above utilizes Barohm ribbon-type high-current resistors.

One of the primary applications of Barohm resistors is for load banks like the one shown in Figure 3-37. Other typical continuous duty applications include: battery charging resistors and rheostats, projection arc rheostats, space heaters and ballast resistors. For high-current intermittent duty uses Barohm resistors are generally unsuited and Edgeohm or groups of Ribflex resistors should be applied.

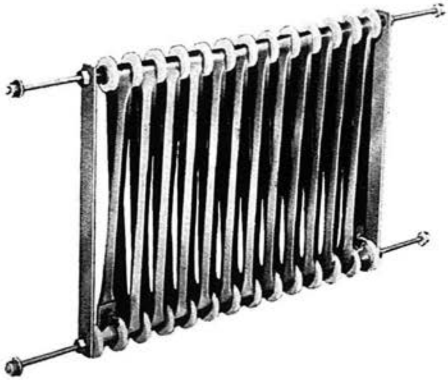


Figure 3-38. Loopohm Resistor without End Frames or Brackets

I. LOOPOHM RESISTORS.

Loopohm resistors, Figure 3-38 are recommended for high-current, continuous-duty applications where mechanical shock and vibration prevail.

1. *Construction*—The Loopohm resistor is essentially a variation of the Barohm resistor previously described. It consists of a channel-shaped alloy resistance ribbon of uniform cross section formed in a series of loops supported between two rods insulated with ceramic bushings and washers. The horizontal rods are spaced and rigidly secured by means of vertical steel support bars.

Each unit is equipped with two end terminals for external connections. Additional taps for intermediate resistance values can be had as shown in Figure 3-39. Clamp-type terminals mounted along the ribbon can be used where adjustability is required.

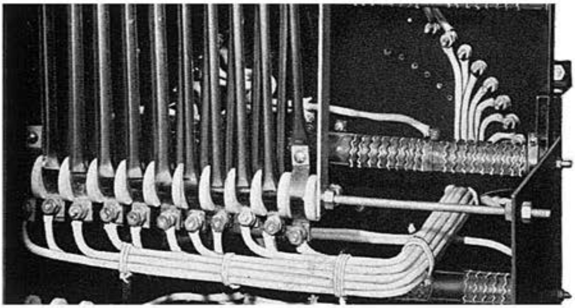


Figure 3-39. Special multi-tapped Loopohm Resistors are shown in foreground

2. *Mountings*—For mounting in control equipment the open-type resistor Figure 3-40a is recommended. For external mounting, singly or in multiples, standard end frames Figures 3-40b and c should be used. Units using end frames have secondary insulation between the two horizontal rods and the end mounting frames, providing double insulation to ground. Loopohm units are also obtainable with expanded or sheet metal enclosures.

3. *Ratings*—Loopohm resistor ratings compare favorably with those for Barohm resistors. The height of Loopohm resistors is standardized at 15 inches while the overall length can be 18½ inches or 23½ inches. These fixed overall dimensions place certain limitations on the range of resistance and current values that can be supplied with Loopohm. Continuous current ratings of standard units range from 110 to 20 amperes. Usual resistance values are from 0.14 to 6 ohms per unit while the standard resistance tolerance is $+ 20 - 10\%$.

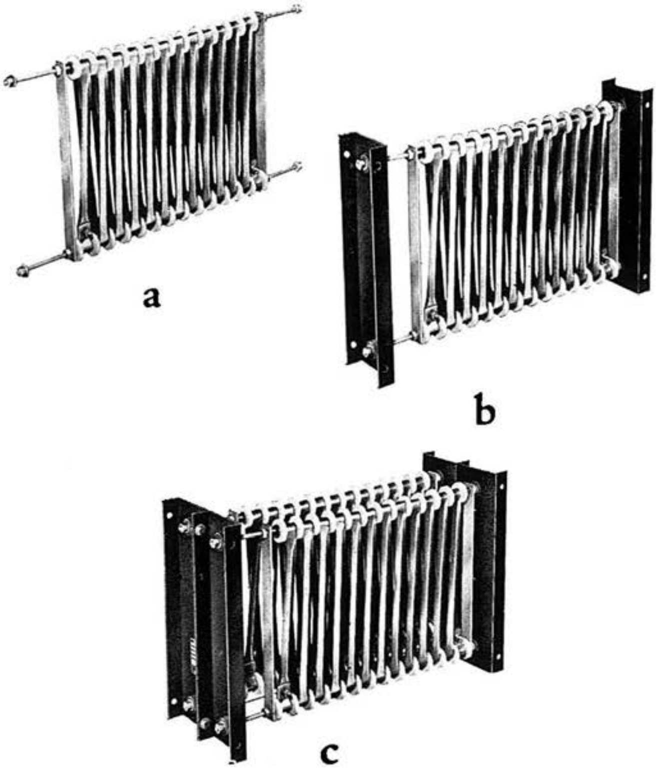


Figure 3-40. Typical Methods of Mounting Loopohm Resistors
a—Open mounting without end frames, b—Open mounting with end frames, c—Multi-deck mounting with end frames.

4. *Performance Data*—Loopohm resistors have practically the same performance characteristics as Edgeohm units under continuous-duty service. Because the alloy ribbon resistive conductor is supported at both ends, Loopohm units are recommended for use in portable and mobile apparatus that is subjected to severe mechanical shock or excessive vibration.

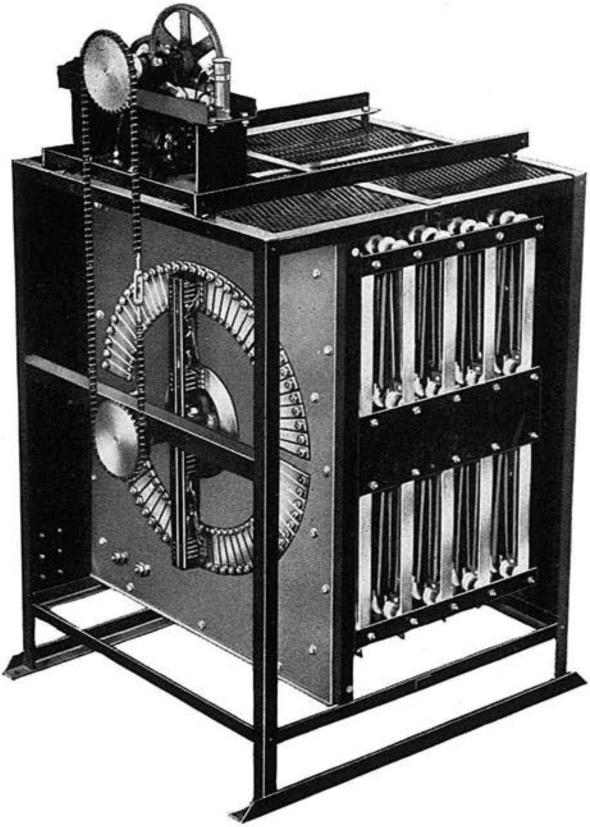


Figure 3-41. Heavy-duty Generator Field Rheostat using Loopohm Resistors

5. *Application Data*—Refer to Barohm application data, Page 98.

J. SPECIAL TYPES OF RESISTORS.

All the power resistors discussed previously are considered standard units, both from the standpoint of design and of the manufacturing processes involved. Besides these types which are ordinarily stocked by the manufacturer in a wide variety of sizes and ratings, there are limitless others that may be considered special types. Many of these special type resistors are so classified because of their limited use in commercial and industrial equipment. Others are considered special types due to their unusual or non-standard construction. Four of the more important special types include: channel, sandbox, coiled wire and Ribohm resistors.

a. Channel-type Resistors.

Channel-type resistors, Figure 3-42, are actually a variation of Ward Leonard Vitrohm pressed steel rheostats. They are made by placing the resistive conductor in an insulated metal pan with a fused-on vitreous enamel.

Connections to the resistor are made by tab or screw-type terminals. Each end of the metal pan has extended ears for mounting purposes.

Sizes of channel resistors are from 2 x 4 inches to 5¼ x 9⅝ inches with watt ratings from 90 to 350 watts respectively, based on a temperature rise of 300°C.

Although channel-type resistors are higher in cost than tubular or strip resistors, they have the advantage of being available with a large number of steps. Steps can be tapered or arranged to meet design requirements. Their high mechanical strength makes them particularly suited for shockproof installations.

Channel resistors are generally applied in voltage and speed regulating equipment, or in conjunction with tap switches to give various resistance values.

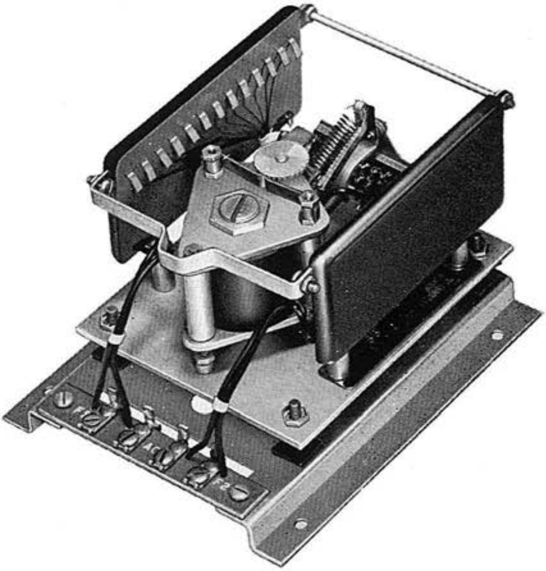


Photo courtesy of Burlington Instrument Co.

Figure 3-42. Multi-tapped Channel-type resistors on the A.C. Rheostatic Direct Acting Voltage Regulator shown, furnish the resistance for automatically adjusting exciter field currents and for dropping the voltage to the solenoid coil.

b. Sandbox Resistors.

Sandbox resistors, Figure 3-43, are sometimes used where high wattages are encountered for extremely short periods of time. These resistors are made of heavy, coiled, alloy wire or crimped ribbon that is fastened to one side of an impregnated asbestos board insulating base. This assembly is placed in a metal box, usually cast iron, and the box is tightly packed with fine quartz sand.

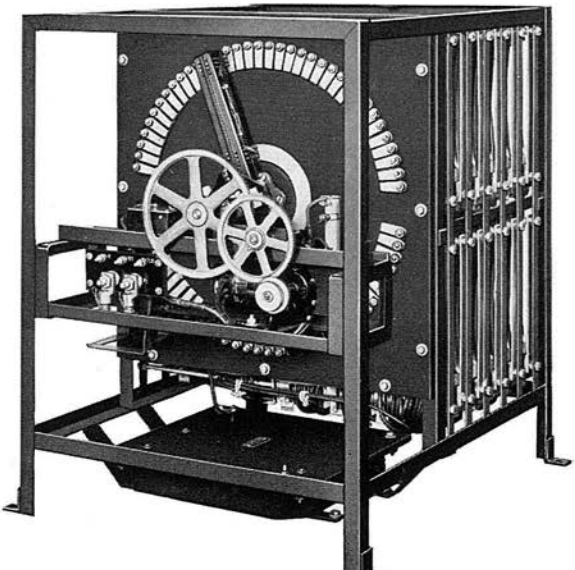


Figure 3-43. Large Sandbox Resistor for field discharge purposes shown in lower front section of Motor Driven Field Rheostat

Since the sand is in direct contact with the entire resistive element, the unit has high heat-absorptive characteristics, increasing the short-time thermal capacity of the resistor and preventing high wattages from damaging the resistive conductor.

Dimensions of sandbox units range from 7 x $8\frac{1}{2}$ x 4 inches to $15\frac{1}{2}$ x 18 x 4 inches. Usual resistance values

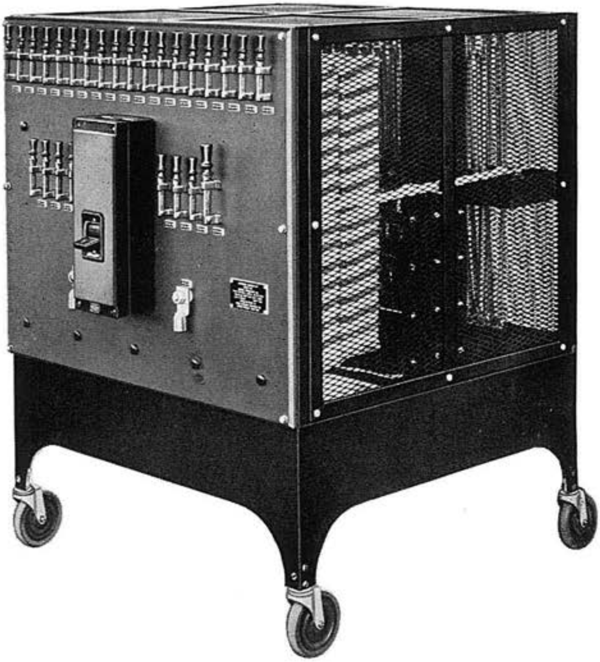


Figure 3-44. Barohm and light-weight coiled-wire resistors are used in the Ward Leonard 30 K.W. portable loading rheostat shown.

are from 0.2 to 25 ohms per unit. Ratings of sandbox resistors are for intermittent duty only, and are based on the constants of the circuits in which they are used.

Sandbox resistors are generally used for field discharge and dynamic braking purposes.

c. Coiled-wire Resistors.

These resistors are used where a low-cost, extremely light-weight resistor is required.

In one method of construction, the coiled resistive conductor is stretched between insulating supports, and connections are made at the support points. Another variation consists of a coiled resistance wire that is wound around a flat, treated, asbestos board. External connections are made to terminals provided at each end of the board or base.

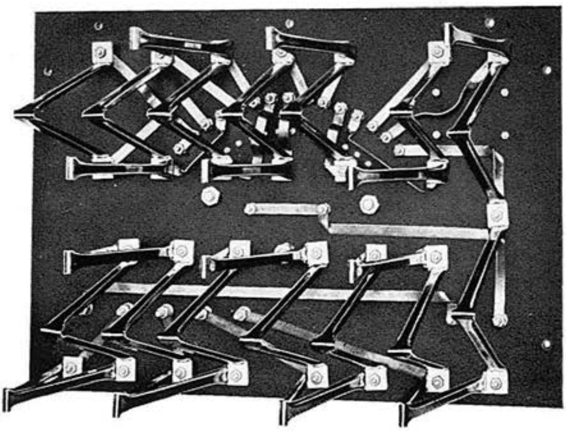


Figure 3-45. Rear view of Face Plate Rheostat using Ribohm Resistors

Coiled-wire resistors are applied primarily for continuous-duty purposes such as in load banks, Figure 3-44. Since these resistors have relatively low heat-absorptive characteristics, they are generally unsuitable for intermittent-duty service.

d. Ribohm Resistors.

Ribohm, a fourth special type resistor, is a variation of the Barohm ribbon resistor. As shown in Figure 3-45, the alloy ribbon resistive conductor is formed into a shallow channel shape for stiffness and then formed into a vee, the ribbon being flat where the bends occur. The ends of the vee-shaped unit are also flat, and punched for securing to the terminal studs.

Ratings of Ribohm resistors, like all unembedded units, are based on a temperature rise of 375°C. Continuous-duty ratings range from 15 to several hundred amperes. The large size units are sometimes applied in high-capacity load banks, or used for face-plate type rheostats. Smaller units are often used as shunts, connected across the series field of a D.C. motor or generator.

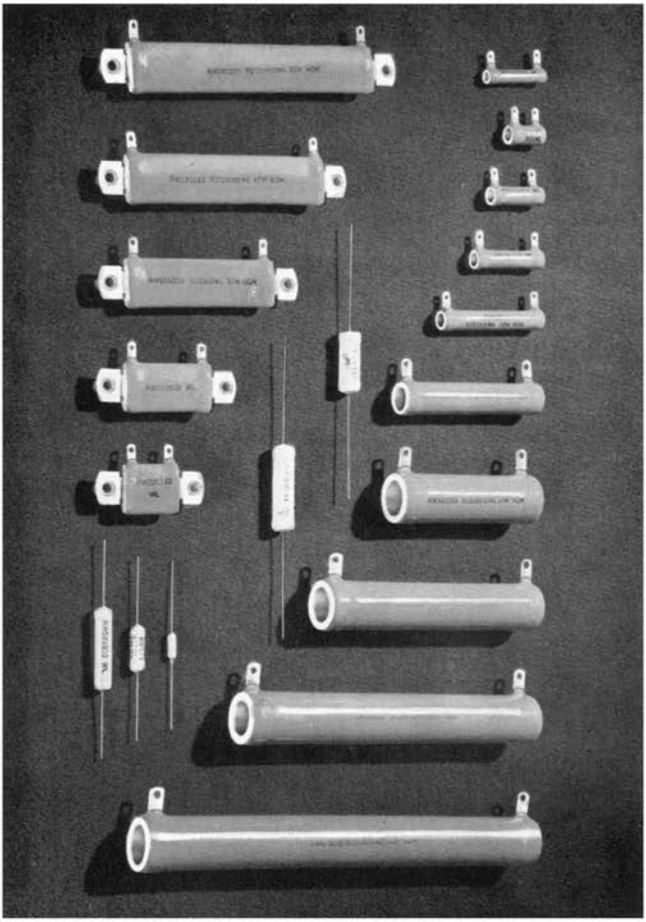


Figure 4-1. Typical Vitrohm power resistors designed and manufactured in accordance with Military Specification MIL-R-26.

CHAPTER IV

Criteria For Selection

A. INTRODUCTION.

Many factors must be considered in the correct selection and application of resistors, and it is imperative that the correct type, wattage rating, resistance value and mounting be chosen to accomplish the desired results. In subsequent paragraphs an endeavor is made to list the more important or critical factors involved and to furnish helpful data for use as a starting point prior to actual tests. Some of the factors and data have been reviewed previously in Chapter III, TYPES OF RESISTORS, and in these instances, further discussion is purposely omitted to avoid repetition.

As mentioned in the introductory chapters, a standard method of testing resistors is established on which catalog ratings are based. In ninety-nine out of one hundred resistor applications, the standard test conditions do not prevail. Four basic factors that should be remembered when applying resistors include:

a. Resistors are generally mounted in housings or enclosures and with other components, thereby restricting free ventilation.

b. Other components may be damaged by heat generated by a resistor.

c. Temperature of components may increase the temperature rise of a resistor beyond a safe value.

d. High momentary surge voltages may cause excessive voltage between resistor coils or windings.

B. GUIDE FOR RESISTOR SELECTION.

When determining the type and rating of a resistor, the following data will serve as a guide:

1. *Load versus Temperature Rise Curves* — These curves for Vitrohm resistors are given on Page 60.

2. *Derating Curves for Various Ambients*—The curves in Figure 4-3 show how the power handling capacity of a Vitrohm resistor is reduced as the ambient temperature rises. For example, a resistor is rated at 100 watts for a 300°C rise, at an ambient temperature of 40°C. If the resistor is operated at an ambient temperature of 100°C, it must be derated by 31 percent, and its actual rating at this ambient temperature (340°C hot spot) is 100 x .69 = 69 watts.

3. *Derating Curve for Various Altitudes*—The curve in Figure 4-4 compares ratings of Vitrohm resistors at various altitudes from sea level up to 80,000 feet, under constant ambient temperature conditions (40°C). From sea level up to 2,500 feet full nominal watt rating is retained, but for higher altitudes the rating of the resistor must be reduced.

In selecting resistors for airborne equipment operating at high altitudes, the derating percentages given in Figure 4-4 are used to further derate in order to compensate for lower atmospheric pressure.

NEMA and ASA recommend that control apparatus designed for operation at altitudes above 6,000 feet, but not above 15,000 feet, shall be derated as follows:

a. Continuous-duty resistors shall be derated to 75 percent of their normal wattage rating.

b. Intermittent- and starting-duty resistors shall be applied on a duty cycle selected on the basis of the next higher "time-on" classification.

4. *Derating Curves for Grouping Resistors* — For Vitrohm tubular resistors see curves on Page 61.

5. *Derating Curves for Enclosures*—Refer to curves on Pages 61 and 63.

6. *Intermittent-duty Curves*—For Vitrohm and Ribflex tubular resistors see Pages 67 and 87 respectively. For Edgeohm resistors refer to Page 94.

7. *Thermal Capacity*—In some applications, using non-embedded resistor construction, it is necessary to

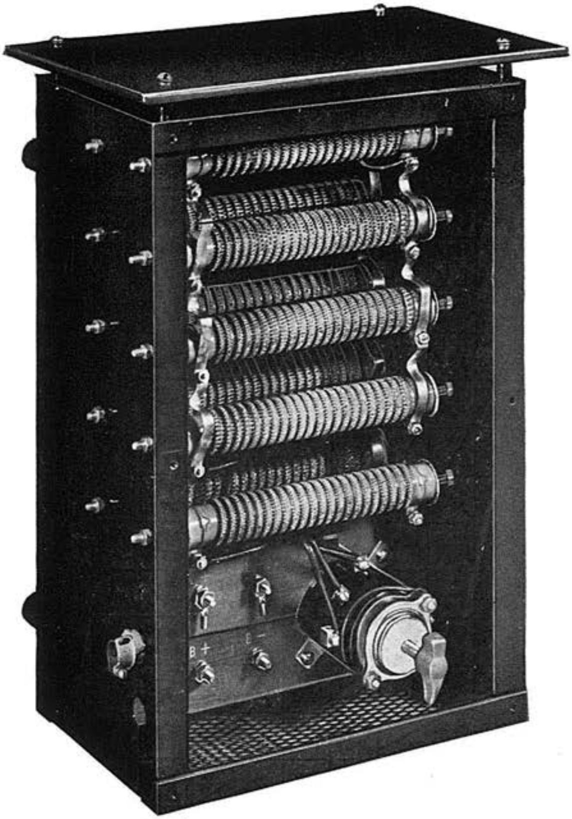


Figure 4-2. Battery Charging Resistor Assembly using Ribflex Resistors mounted in Dripproof Enclosure. Enclosure cover removed.

calculate the temperature rise of resistive conductors that are under load for very short time intervals such as one or two seconds. In such applications the heat-absorption characteristics rather than the radiation or convection qualities become increasingly important.

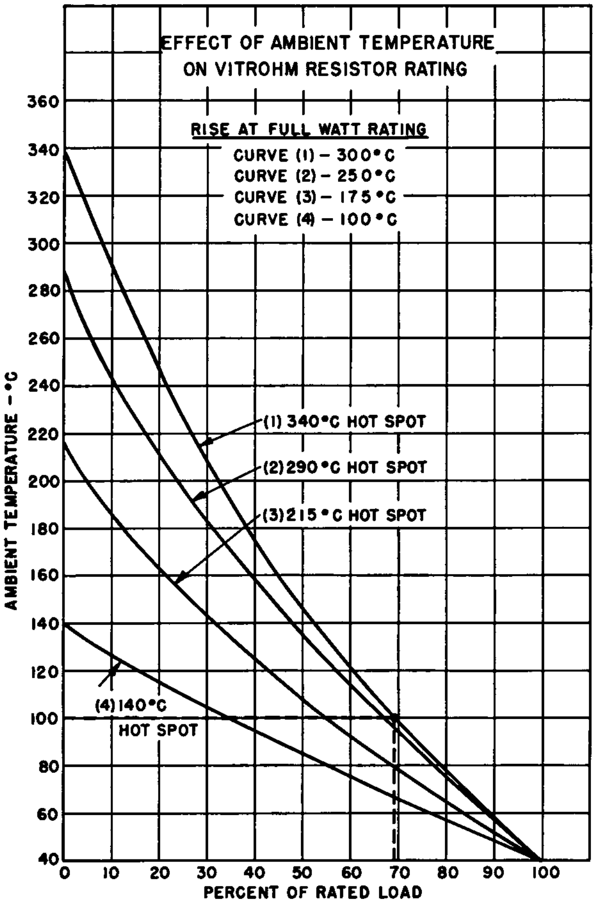


Figure 4-3. Effect of Ambient Temperature on Vitrohm Resistor Rating

Assuming that a ribbon-type resistor such as Edgeohm is subjected to a current of 100 amperes for two seconds, the temperature of the ribbon is calculated as follows:

With a resistive conductor having specific heat of 0.1, a total weight of 0.04 pound and a resistance of 0.1 ohm, the wattage dissipated becomes:

$$W = 100^2 \times 0.1 = 1000 \text{ watts}$$

Since one watt is equivalent to 3.412 BTU per hour, 1000 watts equals 1000 times 3.412 or 3412 BTU per hour. The BTU per 0.04 pound for two seconds is:

$$\frac{2 \times 3412}{0.04 \times 60 \times 60} = 47.4 \text{ BTU}$$

Since one BTU will raise the temperature of one pound of material having a specific heat of unity one degree Fahrenheit, the temperature rise of the ribbon equals:

$$\frac{47.4}{0.1} = 474°\text{F or } 263°\text{C}$$

8. *Maximum Voltage Limitations*—Data for Vitrohm tubular resistors are given on Page 65.

9. *Surge Voltage of Steep Wave Front*—In applications where extremely high-voltage surges of steep wave fronts are known to occur for very short time intervals (milli-seconds), surge-wound resistors should be used. Surge-wound resistors have wider spacings between turns at each end of the tube. This construction is used for protection against high voltages between turns at the ends of the winding. It also affords additional insulation resistance between turns.

10. *Rating versus Number of Taps* — Multi-tapped resistors have the same free-air watt ratings as those with only two end terminals. Because of this it is unnecessary to lower the rating of a resistor with one or more taps. However, multi-section resistors do require derating since the external radiating area is less than that found on multi-tapped units.

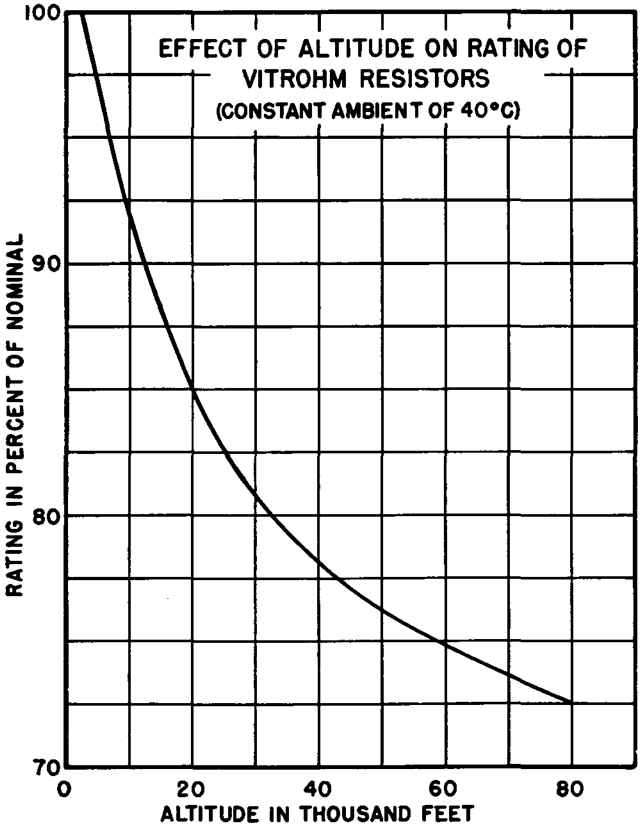


Figure 4-4. Effect of Altitude on the Rating of Vitrohm Resistors

C. ABNORMAL OPERATING CONDITIONS.

In the following paragraphs are discussed several abnormal operating conditions where Vitrohm construction is particularly recommended.

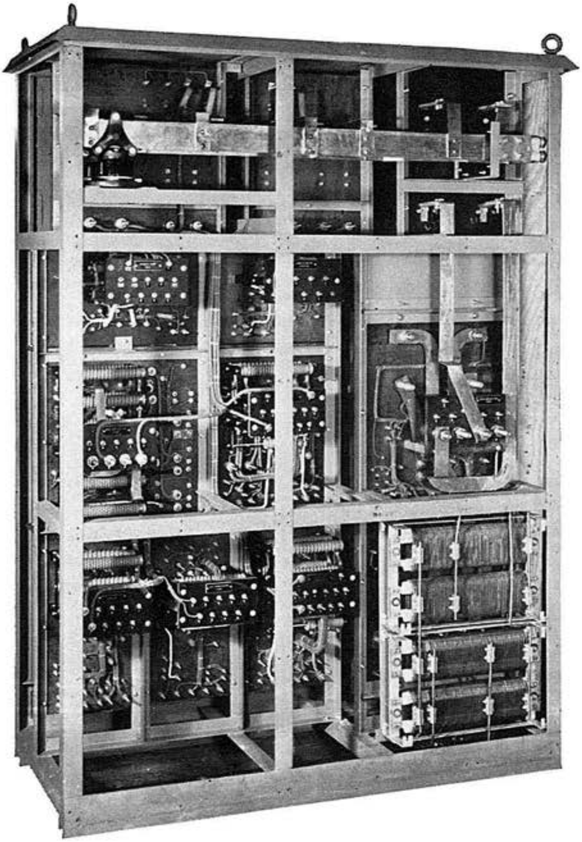


Figure 4-5. D.C. centralized control cubicle for engine room auxiliaries built by Ward Leonard. Banks of Ribflex resistors are used for motor starting and accelerating purposes. For motors above 25 H.P. Edgeohm resistors (lower right) are used.

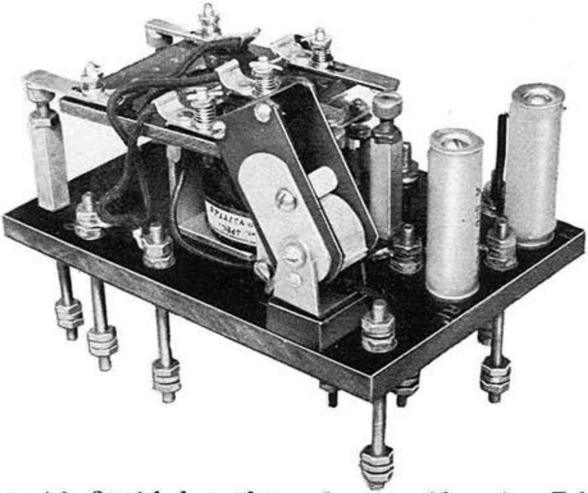


Figure 4-6. Special heavy-duty relay assembly using Tubular Resistors with flexible wire lead terminals

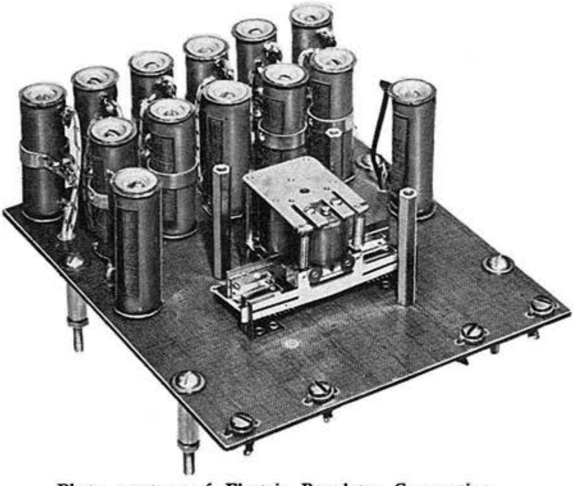


Photo courtesy of Electric Regulator Corporation

Figure 4-7. Miniature direct-acting voltage regulator utilizing Adjustohm tubular resistors

Criteria For Selection

1. *High Humidity* — Resistors operated in damp places, indoors or out, must be protected by a coating which will not permit moisture to enter and cause deterioration to the resistive conductor. The crazeless enamel used in the Vitrohm resistor precludes any possibility of electrolytic action, by completely sealing the resistive conductor against entrance of moisture.

2. *Corrosive Atmosphere*—Many acid or alkali fumes can cause rapid deterioration of a resistor surface, thereby exposing the conductor to the damaging atmosphere. The vitreous enamel of the Vitrohm resistor is resistant to many acids and alkalies and can therefore be operated in such atmospheres without any precautionary measures other than covering the terminals with a protective coating.

3. *Vibration and Shock*—Resistors used in mobile equipment or in locations where severe vibration is encountered must be so constructed that their function will not be impaired. Vitrohm resistors, because they are a homogeneous mass, have great mechanical strength to withstand severe physical shock or continual vibration without damage.

4. *Overloads*—High momentary overload conditions impose considerable strain upon a resistor due to the strong induced magnetic forces. The high heat conductivity and the intimate contact of the vitreous enamel with the resistive conductor of Vitrohm resistors accounts for their ability to withstand heavy momentary overloads.

5. *Salt Atmosphere*—Operation of resistors in the presence of salt atmosphere can prove troublesome unless the resistors are either suitably enclosed, or are capable of withstanding the corrosive action of salt. The protective covering of Vitrohm resistors makes them suitable for operation in such atmospheres without enclosures of any kind.

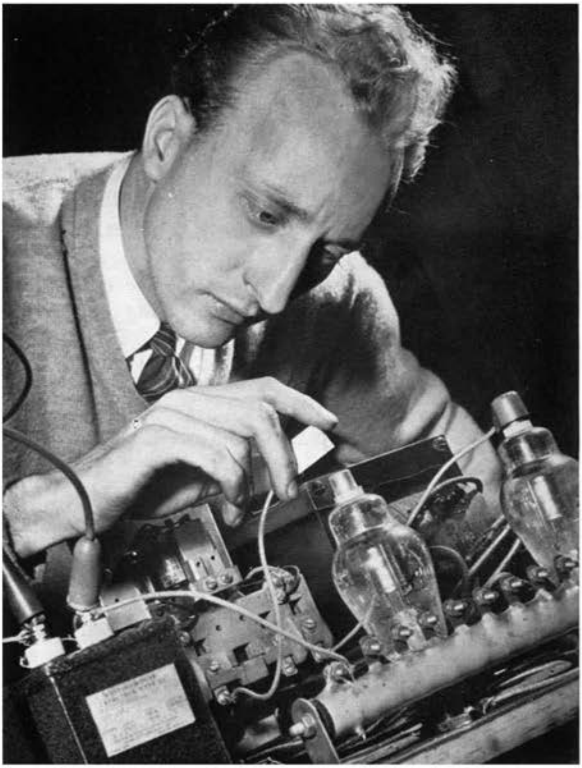


Photo courtesy of Westinghouse Electric Corp.

Figure 4-8. An Ignitron welding control unit used for welding aluminum aircraft subassemblies undergoes test. Vitrohm tapped resistor, a vital component, is illustrated in lower right hand corner.

CHAPTER V

Standard Types and Sizes of Resistors

The following tables show the range of standard stock size power resistors manufactured for use in electronic, industrial and military applications. Wherever possible, stock type resistors should be specified to assure lowest cost and fastest delivery. When stock type resistors will not meet exact application requirements, "made-to-order" resistors can be supplied.

Table 5-1 Axiohm Resistors

Full Watts Rating	Nominal Finished Length A	Length and Type	Nominal Ceramic Core O.D.	Dimension B	Min. Possible Ohms	Max. Possible Ohms Using* .002" wire	Max. Possible Ohms Using* .001" wire	Stand. Term. Type
3	½"	7/16"-Q	5/32"	3/16"	0.10	750	6,000	255
5	1"	7/8"-Y	¼"	11/32"	0.36	1690	14,000	255
10	1¾"	1⅝"-Z	5/16"	13/32"	1.00	6000	50,000	255

*Standard Tolerance 1 Ohm to Maximum Possible Ohms ± 5%. Below 1 Ohm ± 15%.

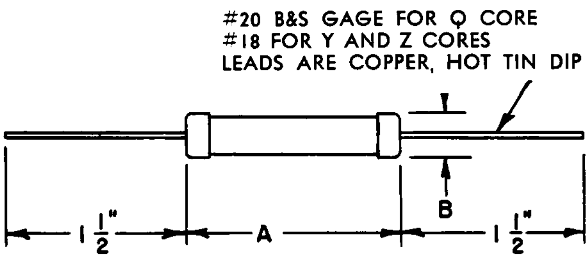


Table 5-2 Vitrohm Tubular Resistors

Full Watts Rating	Length and Type (in inches)	Nominal Diameter Ceramic Core (in inches)		FIXED OR TAPPED•			TAPPED					Standard Terminal Type No.
		Out-side	In-side	Min. Possible Ohms	Max. Possible Ohms		Max. Steps with Various Terminals					
					Using* .002″ Wire	Using* .001″ Wire	3/16″	1/4″	5/16″	7/16″	1/2″	
5†	1 Z	5/16	7/32	0.5	1,360	10,900	1	1	. .	. .	. .	
8	1 1/2 Z	5/16	7/32	0.2	4,170	33,400	2	2	. .	. .	. .	211
10†	1 3/4 Z	5/16	7/32	0.3	5,430	50,000	3	2	. .	. .	. .	
8	1 O	7/16	5/16	0.5	1,890	15,100	1	1	. .	. .	. .	
10	1 1/2 O	7/16	5/16	0.2	5,730	45,800	2	2	. .	. .	. .	211
15	2 O	7/16	5/16	0.3	9,500	76,000	3	2	. .	. .	. .	
20	3 O	7/16	5/16	0.3	16,000	128,000	6	4	. .	. .	. .	
20†	2 T	9/16	25/64	0.3	12,200	100,000	3	2	1	. .	. .	
25	2 1/2 T	9/16	25/64	0.3	16,000	128,000	5	3	2	. .	. .	
32	3 1/2 T	9/16	25/64	0.4	26,800	214,000	7	5	4	. .	. .	
35	4 T	9/16	25/64	0.5	32,900	263,000	8	6	5	. .	. .	211
40	4 1/2 T	9/16	25/64	0.6	36,600	292,000	10	7	4	. .	. .	
45	5 T	9/16	25/64	0.7	41,500	332,000	12	8	6	. .	. .	
55	6 T	9/16	25/64	1.0	51,200	410,000	14	10	8	. .	. .	

25	2 A	5/8	29/64	0.3	10,500	100,000	3	2	1	..	..	219
20	1 9/16 B	3/4	35/64	0.2	8,100	64,800	3	2	7	..	..	
25	2 B	3/4	35/64	0.3	16,300	130,000	3	2	1	..	..	
28	2 5/16 B	3/4	35/64	0.3	20,300	162,000	4	3	2	..	..	
35	3 B	3/4	35/64	0.5	29,300	234,000	6	4	3	2	1	
40	3 1/2 B	3/4	35/64	0.6	35,800	286,000	7	5	4	2	1	219
45	4 B	3/4	35/64	0.7	42,300	338,000	8	6	4	3	2	
50	4 1/2 B	3/4	35/64	0.8	48,800	390,000	10	7	5	3	3	
60	5 B	3/4	35/64	0.9	55,300	442,000	12	8	6	4	3	
70	6 B	3/4	35/64	1.2	68,500	548,000	14	10	8	5	4	
80	6 1/2 B	3/4	35/64	1.3	75,000	600,000	15	11	8	5	5	
60	4 WX	15/16	9/16	0.9	53,000	425,000	8	6	5	3	3	
75	5 WX	15/16	9/16	1.2	69,200	554,000	12	8	6	4	3	252
90	6 WX	15/16	9/16	1.5	85,500	684,000	14	10	8	5	4	

NOTES:† These sizes conform to EIA standards for power wire wound Tubular Type Resistors.

*In selecting high resistance values a reduction in watts rating is necessary due to high voltage limitations. It is recommended that not more than 495 volts R.M.S. (700 V. Peak) per linear inch length of core be applied. In any event the voltage rating shall not exceed $\sqrt{\text{watts x ohms}}$.

•The maximum possible ohms for tapped resistors must be reduced depending on the length of the resistor and the number of steps.

Vitrohm resistors are also available in adjustable and multi-section forms.

Table 5-2 Vitrohm Tubular Resistors (continued)

Full Watts Rating	Length and Type (in inches)	Nominal Diameter Ceramic Core (in inches)		FIXED OR TAPPED•			TAPPED					Standard Terminal Type No.
		Out-side	In-side	Min. Possible Ohms	Max. Possible Ohms		Max. Steps with Various Terminals					
					Using* .002" Wire	Using* .001" Wire	3/16"	1/4"	5/16"	7/16"	1/2"	
120	8 WX	15/16	9/16	2.0	118,000	940,000	19	14	11	7	6	252
150	10 WX	15/16	9/16	2.6	151,000	1,210,000	25	18	14	9	8	
33	2 D	1 1/8	3/4	0.4	24,400	195,000	3	2	1	..	..	
75	4 1/4 D	1 1/8	3/4	1.2	68,500	540,000	9	7	5	3	2	
110	6 1/8 D	1 1/8	3/4	1.8	105,000	840,000	14	10	8	5	4	
115†	6 1/2 D	1 1/8	3/4	1.9	112,000	890,000	15	11	8	5	5	252
160†	8 1/2 D	1 1/8	3/4	2.6	151,000	1,210,000	21	16	12	8	8	
200†	10 1/2 D	1 1/8	3/4	3.2	191,000	1,530,000	26	19	15	10	9	
215	11 3/4 D	1 1/8	3/4	3.6	215,000	1,720,000	29	21	17	11	9	
218	12 D	1 1/8	3/4	3.7	219,000	1,750,000	30	22	17	12	10	
30	AEB	EDISON		0.5	22,000	176,000	..	..	..	..	..	
60	EB	BASE		0.7	44,400	350,000	..	..	..	..	..	
160	DEB	TYPE		2.7	155,000	1,240,000	..	..	..	..	..	..
125	PEB			1.8	106,000	850,000	..	..	..	..	..	
100	HEB			1.5	76,000	600,000	..	..	..	..	..	

NOTES:† These sizes conform to RETMA standards for power wire wound Tubular Type Resistors.
*In selecting high resistance values a reduction in watts rating is necessary due to high voltage limitations. It is recommended that not more than 495 volts R.M.S. (700 V. Peak) per linear inch length of core be applied. In any event the voltage rating shall not exceed $\sqrt{\text{watts x ohms}}$.
•The maximum possible ohms for tapped resistors must be reduced depending on the length of the resistor and the number of steps.
Vitrohm resistors are also available in adjustable and multi-section forms.

Vitrohm Tubular Resistor—Dimensions

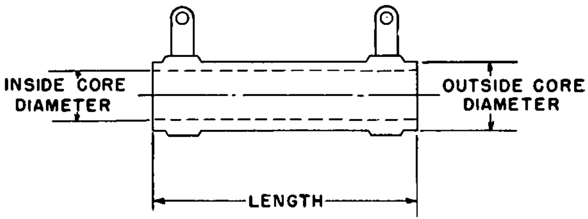


Table 5-3 Stripohm Resistors

Full Watts Rating†	Length (in inches)	FIXED OR TAPPED: Min. Possible Ohms	FIXED OR TAPPED: Max. Possible Ohms Using* .002″ wire	FIXED OR TAPPED: Max. Possible Ohms Using* .0015″ wire	TAPPED: Max. No. of Steps	Stand. Term. Type
20	2	0.5	6,000	12,000	3	
†30	1¼	0.1	6,500	12,800	1	
†40	2	0.2	14,300	28,600	3	
†55	3½	0.4	30,000	59,800	6	235
†65	4¾	0.5	43,000	86,000	9	
†75	6	0.75	57,000	115,000	12	

†Rated sizes conform to RETMA standards for Power Type Strip Resistors.

*In selecting high resistance values a reduction in watts rating is necessary due to high voltage limitations. It is recommended that not more than 495 volts R.M.S. (700 V. Peak) per linear inch length of core be applied. In any event the voltage rating shall not exceed $\sqrt{\text{watts x ohms}}$.

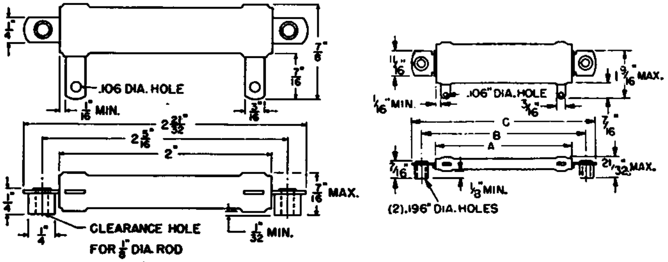


Figure 1

Full Watt Rating	STRIPOHM DIMENSIONS (in inches): A	B	C
20	See Figure 1	See Figure 1	See Figure 1
30	1¼	2	2½
40	2	2¾	3¼
55	3½	4¼	4¾
65	4¾	5½	6
75	6	6¾	7¼

Standard Types And Sizes Of Resistors

Table 5-4 Vitrohm Non-inductive Tubular Resistors

Full Watts Rating	Resistor Type and Length L	Minimum Possible Ohms	Maximum Ohm .002" wire	Std. Term. Type*	DIMENSIONS (in inches) A	B	C	D
10†	1¾" RFZ	0.86	600	211	7/32	5/16	11/64	9/32
20†	2" RFT	1.00	1300	211	3/8	9/16	9/32	15/32
35	4" RFT	0.45	3200	211	3/8	9/16	9/32	15/32
40	3½" RFB	0.50	3300	219	½	¾	23/64	39/64
80	6½" RFB	1.05	7100	219	½	¾	23/64	39/64
75	4¼" RFD	0.90	6100	252	7/8	1⅛	¾	1
160†	8½" RFD	2.05	14,100	252	7/8	1⅛	¾	1

†Rated sizes conform to RETMA Standards for Power Type Strip Resistors.
*Terminals for types RFZ, RFT, RFB and RFD correspond to types Z, T, B or D. Type 200 terminals are unsuitable on Non-inductive resistors.

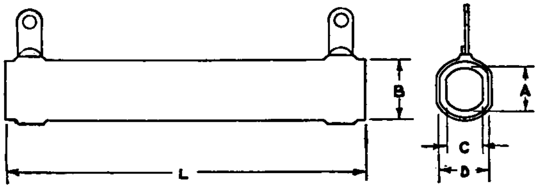


Table 5-5 Plaqohm Resistors

Full Watts Rating	Min. Possible Ohms	Max. Recom. Ohms .002" wire	Max. Possible Ohms .0014" wire	Max. No. Steps	DIMENSIONS (in inches) A	B	C	D	E	F
25	0.5	3,100	11,500	2	3 1/16	2 15/32	1¼	½	3/16	5/16
50	1.0	5,200	19,200	4	4⅝	4 1/16	1¼	½	3/16	3/8
150	4.0	23,400	86,400	4	5¾	5 1/32	3	19/32	7/32	7/16

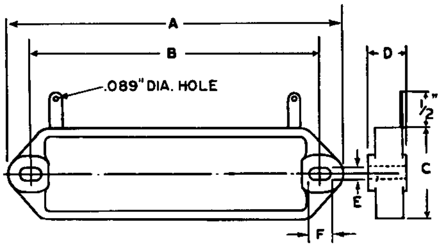
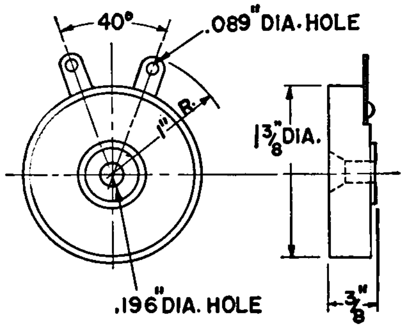


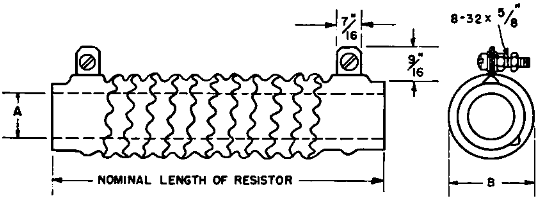
Table 5-6 Discohm Resistors

Full Watts* Rating	Min. Possible Ohms	Max. Recomm. Ohms .002" Wire	Max. Possible Ohms .0014" Wire
24	1.0	1740	5760

NOTE—*For single unit.



Ribflex Resistor—Dimensions



Note—Resistor dimensions are shown with Type 201 Terminals. Refer to Page 135 for dimensions of other terminals.

Table 5-7 Ribflex Resistors

Full Watts Rating	Length and Type (in inches)	FIXED OR TAPPED: Minimum Possible Ohms	FIXED OR TAPPED: Maximum Possible Ohms with Single Step	FIXED OR TAPPED: Maximum Possible Ohms with Maximum No. Steps	Tapped Maximum Number of Steps	Standard Term. Type	DIMENSIONS (in inches) A	DIMENSIONS (in inches) B
75	3½ B	0.04	6.0	6.0	1	201	17/32	1
110	4½ B	0.04	9.0	7.0	2			
125	5 B	0.05	10.0	9.0	2			
160	6½ B	0.06	15.0	11.0	3			
120	4 WX	0.05	9.0	7.0	2	201	9/16	1 3/16
145	5 WX	0.06	13.0	11.0	2			
175	6 WX	0.05	16.0	12.0	3			
235	8 WX	0.08	24.0	15.0	5			
155	4¼ D	0.05	12.0	10.0	2	201	¾	1⅜
225	6⅛ D	0.08	18.0	13.0	3			
240	6½ D	0.09	22.0	17.0	3			
300	8½ D	0.11	33.0	23.0	5			
375	10½ D	0.15	40.0	30.0	5			
420	11¾ D	0.18	50.0	40.0	5			
400	8½ V	0.20	45.0	30.0	5	224	1⅛	1⅞
500	10½ V	0.26	57.0	42.0	5			
550	11¾ V	0.30	66.0	50.0	5			

Table 5-8 Edgeohm Resistors

Continuous Ampere Capacity	RESISTANCE IN OHMS Length A— 5⅞″	Length A— 9¼″	Length A— 12½″	Length A— 15¾″	Length A— 19″
21	0.70	1.55	2.50	3.50	4.40
24	0.55	1.20	2.00	2.75	3.40
27	0.45	0.98	1.60	2.20	2.70
30	0.35	0.79	1.30	1.75	2.20
32	0.30	0.70	1.10	1.55	1.90
36	0.25	0.52	0.84	1.18	1.50
39	0.20	0.46	0.75	1.03	1.30
44	0.17	0.36	0.58	0.80	1.00
48	0.15	0.28	0.46	0.63	0.80
51	0.13	0.25	0.41	0.56	0.70
58	0.11	0.22	0.36	0.50	0.65
62	0.09	0.18	0.29	0.40	0.50
66	0.08	0.16	0.26	0.35	0.45
70	0.07	0.14	0.23	0.31	0.50
79	0.05	0.12	0.20	0.28	0.35

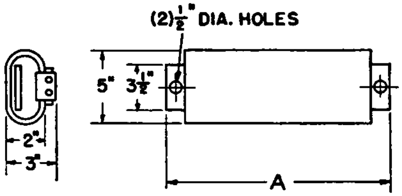


Table 5-9 Barohm Resistors

Continuous Ampere Rating	RESISTANCE IN OHMS		
	Height A—16″	Height A—20″	Height A—24″
20	4.7	5.9	7.0
25	3.2	4.0	4.8
30	2.65	3.3	4.0
40	1.6	2.0	2.44
45	1.3	1.6	1.95
50	1.0	1.3	1.55
60	0.82	1.0	1.23
70	0.57	0.71	0.85
75	0.45	0.56	0.67
85	0.35	0.45	0.53
100	0.31	0.38	0.46
115	0.24	0.30	0.37
130	0.19	0.24	0.29
145	0.15	0.19	0.23

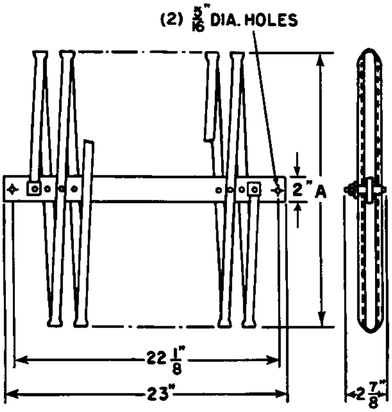
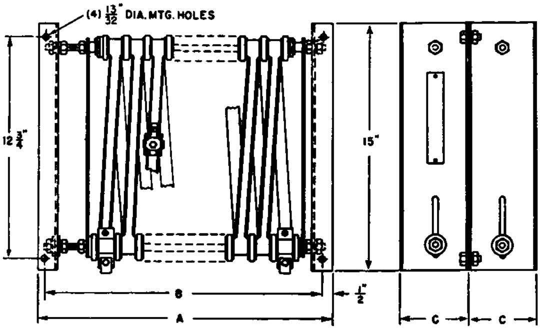


Table 5-10 Loopohm Resistors

Continuous Ampere Rating	RESISTANCE IN OHMS	
	Width A—18½″	Width A—23½″
20	4.12	5.88
25	2.82	4.0
30	1.96	2.94
35	1.18	1.77
40	0.94	1.41
45	0.73	1.10
50	0.59	0.89
60	0.41	0.62
70	0.32	0.49
80	0.26	0.38
85	0.22	0.33
95	0.18	0.27
110	0.14	0.21

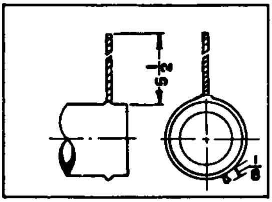
Note: Dimension C is 4 inches.



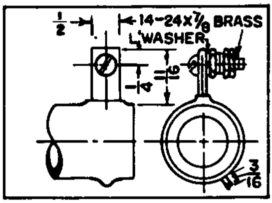
Standard Types and Sizes of Resistors

Typical Vitrohm Resistor Terminals

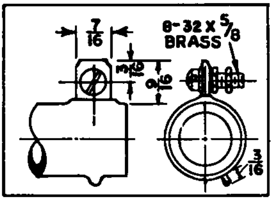
(Dimensions in Inches)



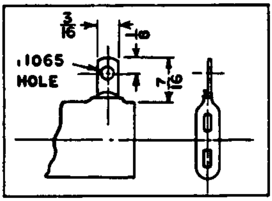
TERMINAL No. 200
For all sizes



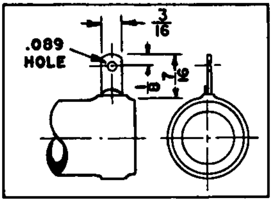
TERMINAL No. 224
For sizes B, WX, D & V.



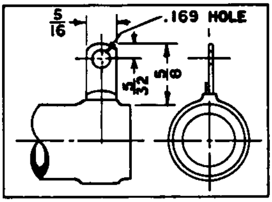
TERMINAL No. 201
For sizes B, WX, & D.



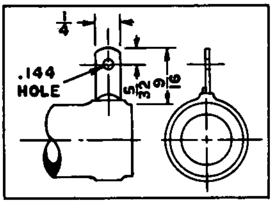
TERMINAL No. 235
For all sizes and Stripohm



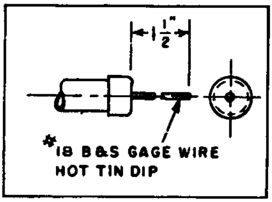
TERMINAL No. 211
For all sizes



TERMINAL No. 252
For sizes T, A, B, WX & D.



TERMINAL No. 219
For all sizes



TERMINAL No. 255
For sizes Y & Z
For Q cores lead is
#20 B & C gage.

CHAPTER VI

The Making of a Vitrohm Resistor

1. *Introduction*—Prior to the use of embedded wire-wound resistors, wire was wound on a porcelain rod or asbestos covered metal tube without any protection for the wire from corrosive or oxidizing effects of the atmosphere in which it was operated.

As resistors became more widely used the need for improvement in design and construction became obvious. Early research and experiment indicated the necessity for manufacturing resistors capable of dissipating more heat energy, dissipating it faster and thereby making it possible to reduce the unit size.

Results of tests made were not at first fully appreciated nor were the difficulties fully and immediately overcome. Time and experience gradually showed that there are four basic elements that are of prime importance to satisfactory operation of a wire-wound resistor. They are the core, the terminals, the resistive conductor, and the coatings.

2. *Ceramic Core*—Cores of every known description were tried with refractory ceramic cores always showing up best. Properly made and vitrified, they withstand shock and vibration, resist penetration of moisture and provide an adequate medium for the dissipation of heat.

There are many industrial ceramics with widely varying characteristics. Among the more important characteristics, insofar as they affect resistor performance, are mechanical strength, high density, and good thermal conductivity. Thermal expansion and contraction of the ceramic core must be properly correlated with the corresponding thermal properties of the other components

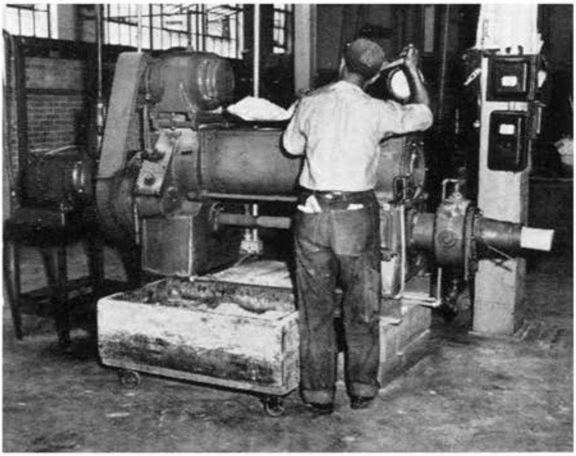


Figure 6-1. The refractory material is mixed and "de-aired" in this automatically controlled pugging machine.

of a complete resistor. The ceramics made for Vitrohm must possess all of these qualities, not perhaps to the fullest degree in any one particular, but to the greatest degree possible in all particulars.

The Vitrohm resistor ceramic core in the initial stage of manufacture, consists of finely ground powders which are thoroughly mixed with a binder. The mixture is formed into pugs, under high pressure, in a pug mill, Figure 6-1. The pugs are then placed in an extruding machine, Figure 6-2, which shapes the pugs, in an extruding die, into hollow tubes about six feet long. The tubes are supported on steel mandrels to preserve their uniformity of shape and the accuracy of inside and outside dimensions. After oven drying the long tubes are cut to the required lengths, placed on racks, and then vitrified in long, gas-fired, conveyor, tunnel kilns, Figure 6-3. Kiln temperatures are automatically controlled from start to finish.

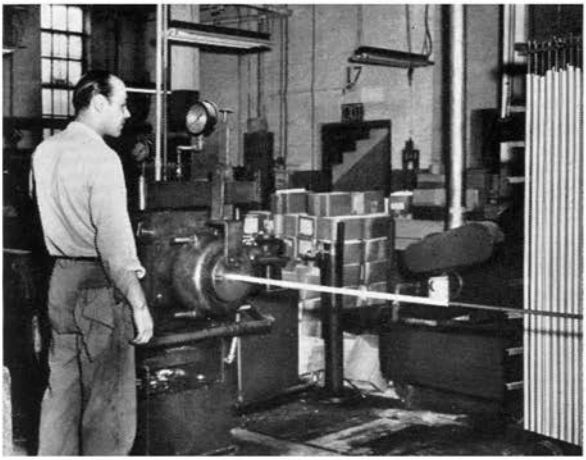


Figure 6-2. Long tubes of refractory material are extruded from hydraulic presses. Note extreme precautions to insure straight cylindrical tubes.

Figure 6-3. Extruded tubes, dried and cut to length, are fired for vitrification in this specially-designed high temperature controlled kiln.

On completion of the firing process the refractory tubes which may be cylindrical, oval in shape, cylindrical with flatted sides, or in other shapes, depending on the type of resistor, are segregated by size, length and general type. The tubes then undergo a thorough inspection that includes gauging of inside and outside diameters, eccentricity and longitudinal camber. Inspection also includes examination of tube surfaces to assure a smooth winding area. Further checks to determine that the proper degree of vitrification has been reached include a sampling test for porosity and an expansion check on an interferometer. The approved refractory core is then ready for use in the production of Vitrohm resistors.

3. *Terminals*—The terminals to be affixed to the refractory tubes are especially chosen to insure proper expansion and adhesion to the enamel and ceramic core. Most of the terminals used on Vitrohm resistors are banded to the tube by spot welding to insure a uniformly tight and positive adherence to the tube, eliminating any possibility of shifting in the firing process.

4. *Resistive Conductor*—The tube, with its terminals attached, is then ready for the winding operation. The resistor to be wound is centered in the winding machine. Directly below is located a lead screw, preselected to provide the proper winding pitch for the particular resistor being wound. The pitch is the spacing or number of turns of wire per inch of core length.

The alloy resistance wire, also preselected as to alloy and gauge, is fed from a spool over an automatic tension device and a guide, and attached to one end terminal. The winding machine is then started and the lead screw moves the guide along the tube, winding the resistance wire uniformly on the core.

With two terminal resistors only one winding is used. On some tapped resistors or multi-section units, differ-

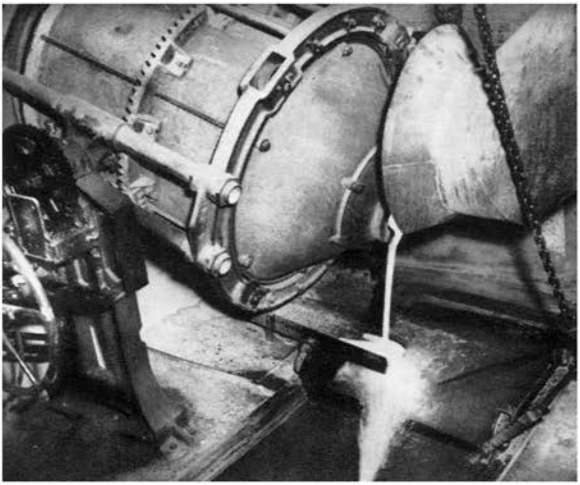


Figure 6-4. Vitrohm enamel being fritted. White hot, the vitreous enamel is poured into a cold bath to break up the mass into small particles.

ent wire sizes, alloys, or winding pitches may be used for each step.

The correct winding is obtained either by using a turns counter, or by continuously balancing the winding against a master in a bridge circuit. The resistor is checked for resistance tolerance and all resistor wire-to-terminal joints are then spot welded. The resistor is now ready for the enameling process.

5. *Coating* — The vitreous enamel is prepared by weighing out the proper ingredients and fritting the mixture, Figure 6-4. The frit is then ground, Figure 6-5, to a fine powder; the fineness of the powder is checked by sifting it through a bank of sieves, and the residue on each sieve is then rechecked. The enamel powder is then suspended in a liquid to obtain the proper con-

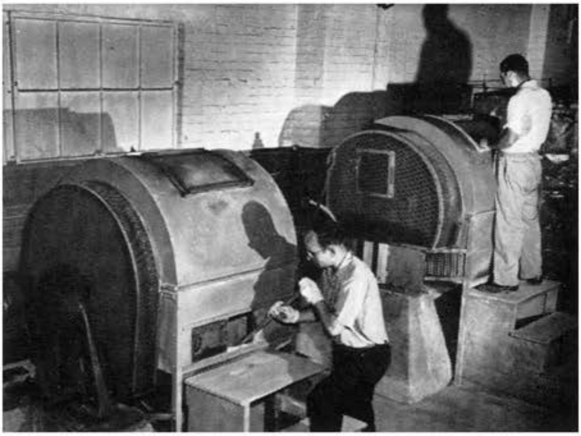


Figure 6-5. These revolving "ball mills" grind the frit to the exact fineness needed to produce perfect Vitrohm (vitreous enamel).

sistency for coating the resistor. Each batch of enamel is checked for its expansion characteristics on an interferometer, Figure 6-6.

After the resistor has been completely coated with enamel, except for the upright portion of the terminals, it is placed in a rack and the enamel is allowed to dry. Then the bore and ends of the core are brushed to remove any enamel from these surfaces before the firing operation. Precautions are also taken to prevent the enamel from adhering to the exposed portion of terminals.

The resistor is then placed on a rod along with many others and the rod is suspended on a conveyor belt or rack that travels at a uniform rate through the enameling furnace, Figure 6-7. The long conveyor furnaces used in the manufacture of Vitrohm resistors have a

Figure 6-6. Vitreous enamel being measured by interferometer method for coefficient of thermal expansion, melting point and annealing point.*

*This particular interferometer was one of the first built by the U. S. Bureau of Standards.

Figure 6-7. Resistors passing through the Enameling furnace where the Vitrohm enamel coating is vitrified.

pre-heat section, a high-heat section and a post-heat section. In this way the resistor is slowly brought up to firing temperature and gradually cooled to avoid stressing the resistor core or enamel. When the resistor reaches the center of the conveyor furnace, the temperature is such that the Vitrohm enamel becomes vitrified. Furnace temperatures are automatically controlled, recorded, and maintained between very close limits to insure the complete vitrification of the enamel.

After the resistor leaves the furnace, the terminals are cleaned. Some types of terminals are tinned while others are equipped with screws, nuts, bolts, lugs, or other hardware, as specified by the customer.

6. *Inspection*—The resistor is next checked for resistance value and adherence to tolerance limits. It is then marked for identification and resistance value.

After a final inspection to assure full conformity with the manufacturing or customer specifications for that

Figure 6-8. A test length of resistance wire is being processed in the combustion furnace to determine carbon and sulphur content and insure accuracy of alloy formula.

The Making Of A Vitrohm Resistor

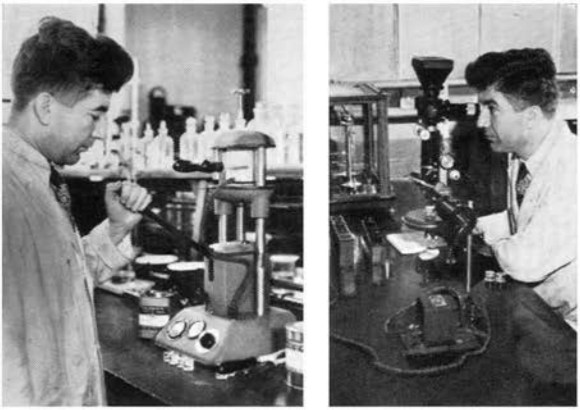


Figure 6-9. Minute pieces of metal samples, imbedded in plastic mounts, are microscopically studied for grain and crystal structure.

Figure 6-10. Electro-chemical analyzer checks metals and all incoming raw materials for conformity with specifications to insure uniform quality.

particular resistor, the unit is carefully packed for shipment.

7. *Quality Control*—The resistor manufacturing process outlined in previous paragraphs appears to be relatively simple but actually is quite complex. Uniformly high quality can be assured only by constant laboratory testing of all raw materials and finished components, as well as by close control over all manufacturing processes. Several of these tests and controls are indicated in the accompanying photographs.

CHAPTER VII

Resistor Standards

A. GENERAL.

Despite the long history of resistor manufacture and use, development of industry-wide standards for resistors is only now receiving serious consideration. The National Electrical Manufacturers Association (NEMA) has developed standards, generally recognized and accepted, though limited in application. These are presented here as the basic standards.

The Radio-Electronics-Television Manufacturers Association (RETMA) is presently engaged in the development of more comprehensive standards involving resistor dimensions, values, tolerances, power ratings, styles, markings, tests, materials and construction. However, these RETMA standards have not as yet been approved by the industry, or put into general use and therefore are not presented here.

The importance of U. S. Government standards or specifications for resistors built for use in military and associated equipment should not be overlooked by those applying resistors. The latest government specifications, including up-to-date revisions, should always apply. Due to their broad scope and the fact that such specifications are constantly undergoing slight modification, no attempt is made to review any of the U. S. Government specifications for resistors.

However, for the convenience of those readers interested in the application of resistors in military equipment, a partial listing of U. S. Government specifications for resistors is given in the Bibliography and Reference Section, Page 193.

B: NEMA STANDARDS.
RESISTORS—RATING STANDARDS

IC1-13.01 Rating of Resistors—Resistors shall be rated in ohms, amperes and class of service.

IC1-13.02 Service Classification of Resistors—A. Resistors shall be designated by class numbers in accordance with the Tables 1, 2, 3 and 4. (Table 4 omitted.)

B. Starting and intermittent-duty resistors are primarily designed for use with motors which require an initial torque corresponding to the stated per cent of full-load current on the first point and which require an average accelerating current (rms value) of 125 per cent of full-load current.

With a secondary-resistor alternating-current controller, the figures given in the tables for the percent of full-load current on the first point, starting from rest, apply to rotor (secondary) current and to torque. The primary current will, in general, be a higher percentage of the full-load current.

C. Starting and intermittent-duty primary resistors which are designed for use with squirrel-cage motors and which meet the test described in IC1-13.12 are included in the tables.

D. Continuous-duty resistors shall be capable of carrying continuously the current for which they are designed.

E. An adjustable-speed motor having a given horsepower rating, when started with full field, generally requires a resistor having large ohmic value than does a constant-speed motor of the same horsepower rating. For this reason, the current on the first point and the capacity of the complete resistor of the same NEMA classification for an adjustable-speed motor may be different from that for a constant-speed motor of the same horsepower.

NOTE—A continuous-duty resistor will be so designed that the controller may be operated continuously on any point when the load follows its normal speed-torque curve, except that it must not be operated continuously below the minimum speed specified.

Resistor Standards

Table I Class Numbers of Resistors

For non-reversing service and reversing non-plugging service without armature shunt or dynamic braking

Approx. Per Cent of Full Load Current on First Point Starting from Rest.	Class Numbers Applying to Duty Cycles						
	5 Sec. On 75 Sec. Off	10 Sec. On 70 Sec. Off	15 Sec. On 75 Sec. Off	15 Sec. On 45 Sec. Off	15 Sec. On 30 Sec. Off	15 Sec. On 15 Sec. Off	Continuous Duty
25	111	131	141	151	161	171	91
50	112	132	142	152	162	172	92
70	113	133	143	153	163	173	93
100	114	134	144	154	164	174	94
150	115	135	145	155	165	175	95
200 or over	116	136	146	156	166	176	96

When an armature shunt resistor is added, the class number shall include the suffix AS.

EXAMPLE—Class 155AS is a resistor which includes an armature shunt and which will allow an initial inrush of 150 per cent with the armature shunt open.

When a dynamic braking resistor is added the class number shall include the suffix DB.

EXAMPLE—Class 155DB.

Table II Class Numbers of Resistors

For reversing plugging service without armature shunt or dynamic braking

Approx. Per Cent of Full-Load Current on First Point Starting from Rest with all Resistance in circuit	Class Numbers Applying to Duty Cycles			
	15 Sec. On 45 Sec. Off	15 Sec. On 30 Sec. Off	15 Sec. On 15 Sec. Off	Continuous Duty
25	151 P	161 P	171 P	91 P
50	152 P	162 P	172 P	92 P
70	153 P	163 P	173 P	93 P
100	154 P	164 P	174 P	94 P

NOTE—The class numbers apply to the complete resistor, but the duty cycles apply to the accelerating resistor only.

When an armature shunt resistor is added, the class number shall include the suffix AS.

EXAMPLE—Class 153P-AS is a plugging resistor which includes an armature shunt and which will allow an initial inrush of 70 per cent with the armature shunt open.

When a dynamic braking resistor is added the class number shall include the suffix DB.

EXAMPLE—Class 153P-DB.

Table III Class Numbers of Resistors

For dynamic lowering crane and hoist controllers

Approx. Per Cent of Full-Load Current on First Point Hoisting Starting from Rest without Armature Shunt	Class Numbers Applying to Duty Cycles			
	15 Sec. On 45 Sec. Off	15 Sec.On 30 Sec. Off	15 Sec. On 15 Sec. Off	Continuous Duty
50	152 DL	162 DL	172 DL	92 DL
70	153 DL	163 DL	173 DL	93 DL

PERFORMANCE STANDARDS

IC1-13.10 Temperature of Resistors—When a temperature test is made on a resistor, rheostat or dimmer, at the current values, duty cycle and elapsed time specified, the temperature rise above the ambient temperature and the methods of temperature measurement shall be in accordance with following:

1. For bare resistive conductors, the temperature rise shall not exceed 375 C as measured by a thermocouple in contact with the resistive conductor.
2. For resistor units, rheostats, and wall-mounted rheostatic dimmers, which have an imbedded resistive conductor the temperature rise shall not exceed 300 C as measured by a thermocouple in contact with the surface of the embedding material.
3. For rheostatic dimmers which have embedded resistive conductors and which are arranged for mounting on switchboards or in noncombustible frames, the temperature rise shall not exceed 350 C as measured by a thermocouple in contact with the surface of the embedding material.
4. The temperature rise of the issuing air shall not exceed 175 C as measured by a mercury thermometer at a distance of one inch from the enclosure.

IC1-13.11 Temperature Test—Resistors—A. When a temperature test is made on a starting- or intermittent-duty resistor without its motor, the resistor shall be connected to a voltage which will give the initial inrush current specified, the steps shall be cut out at equal intervals of time in the time-on period of the cycle specified, and the current shall be maintained at 125 per cent of the full-load current for those steps through which 125 per cent of full-load current can flow. The specified cycle shall be repeated for one hour.

B. When a temperature test is made on a continuous-duty resistor without its motor, any tested step shall be subjected to 100 per cent of the current for which the resistor is designed, and this value of current shall be maintained until the maximum temperatures are reached.

C. When a temperature test is made on a rheostatic dimmer, it shall be made on a single plate which is operated at rated voltage, and connected in series with lamps totalling the rated lamp load.

NOTE—Single plates meeting this test will operate at safe temperatures when assembled into switchboard groups because of the diversity of loading of the various plates. The maximum temperature rise may be approximated by setting the lever so that the dimmer is dissipating maximum wattage.

IC1-13.12 Temperature Test—Primary Resistors for Squirrel-Cage Motors—When a temperature test is made on a general-purpose single-step primary starting resistor for a squirrel-cage motor, the resistor shall be tested with 300 percent of normal full-load current of the motor for which the resistor is designed, and the current shall be maintained for a duty cycle as indicated in the resistor classification. This cycle shall be repeated for one hour, after which period the temperature rise shall not exceed the limitations given in IC1-13.10.

APPLICATION STANDARDS

IC1-13.20 Resistor Application Table—The following table is intended as a guide in specifying or designing resistors. The classifications are those which experience has shown to be correct for the average installation. It is recognized that there will be exceptions. The table applies to resistors composed of wire-wound units or cast grids. It is also applicable to unbreakable resistors provided that the time-on period does not exceed the values given in IC1-13.02. The table gives the basic class number. Where plugging, dynamic braking, armature shunt or dynamic lowering functions are required, the appropriate suffix letters given in IC1-13.02 should be added to the basic number.

INSTALLATION	CLASS NUMBER OF RESISTOR
BLOWERS —	
Centrifugal	133--93
Constant-Pressure	135--95
BRICK PLANTS —	
Augers	135
Conveyors	135
Dry Pans	135
Pug Mills	135
BY-PRODUCTS COKE PLANTS—	
Door Machine	153
Leveler Ram	153
Pusher Bar	153
Valve Rev. Machines	153
CEMENT MILLS —	
Conveyors	135
Crushers	145
Elevators	135
Rotary Dryers	145--95
Grinders—Pulverizers	135
Kilns	135--95
COAL AND ORE BRIDGES —	
Bridge	153
Closing	162
Holding	162
Trolley	162 and 163

RESISTOR APPLICATION TABLE (continued)

INSTALLATION	CLASS NUMBER OF RESISTOR
COAL MINES —	
Car Hauls	162
Conveyors	135--55
Cutters	135
Crushers	145
Fans	134--93
Hoists—slope	172
—vertical	162
Jigs	135
Picking Tables	135
Rotary Car Dumpers	153
Shaker Screens	135
COMPRESSORS —	
Constant-Speed	135
Varying Speed—centrifugal	93
—plunger-type	95
CONCRETE MIXERS	135
CRANES—Service Classes I, II and III	
Hoist	152 & 153
Bridge or Trolley—Roller Bearings	152
Sleeve Bearings	153
CRANES—Service Classes IV and V	
Hoist	162 & 163
Bridge or Trolley with	
Sleeve Bearings	163
Roller Bearings	162
FLOUR MILLS —	
Line Shafting	135
FOOD PLANTS —	
Butter Churns	135
Dough Mixers	135

RESISTOR APPLICATION TABLE (continued)

INSTALLATION	CLASS NUMBER OF RESISTOR
Hoists —	
Winch	153
Mine Slope	172*
Mine Vertical	162*
Contractor's Hoists	152
Larry Cars	153
Lift Bridges	152
Machine Tools —	
Bending Rolls	163--164
Boring Mills	135
Bull Dozers	135
Drills	115
Gear Cutters	115
Grinders	135
Hobbing Machines	115
Lathes	115
Milling Machines	115
Presses	135
Punches	135
Saws	115
Shapers	115
Metal Mining —	
Ball—Rod—Tube Mills	135
Car Dumpers—Rotary	153
Converters—Copper	154
Conveyors	135
Crushers	145
Tilting Furnace	153
Paper Mills —	
Beaters	135
Calenders	154--92
Pipeworking —	
Cutting and Threading	135
Expanding and Flanging	135--95

*See also Standard ICI-45.01.

RESISTOR APPLICATION TABLE (continued)

INSTALLATION	CLASS NUMBER OF RESISTOR
Power Plants —	
Clinker Grinders	135
Coal Crushers	135
Conveyors—Belt	135
—Screw	135
Pulverized Fuel Feeders	135
Pulverizers—Ball-Type	135
—Centrifugal	134
Stokers	135--93
Pumps —	
Centrifugal	134--93
Plunger	135--95
Rubber Mills —	
Calenders	155
Crackers	135
Mixing Mills	135
Washers	135
Steel Mills—	
Accumulators	153
Casting Machines—Pig	153
Charging Machines—Bridge	153--163
—Peel	153--163
—Trolley	153--163
Coiling Machines	135
Converters—Metal	154
Conveyors	135--155
Cranes—See Cranes Class V on page 153	
Crushers	145
Furnace Doors	155
Gas Valves	155
Gas Washers	155
Hot Metal Mixers	163
Ingot Buggy	153
Kickoff	153

RESISTOR APPLICATION TABLE (continued)

INSTALLATION	CLASS NUMBER OF RESISTOR
Levelers	153
Manipulator Fingers	153--163
Pickling Machine	153
Pilers—Slab	153
Racks	153
Reelers	135
Saws—Hot or Cold	155
Screw Downs	153--163
Shears	155
Shuffle Bars	155
Side Guards	153--163
Sizing Rolls	155
Slab Buggy	155
Soaking Pit Covers	155
Straighteners	153
Tables—Approach	153
—Lift	153--163
—Main Roll	153--163
—Roll	153
—Shear Approach	153--163
—Transfer	153
Tilting Furnace	153
Wire Stranding Machine	153
Woodworking Plants —	
Boring Machines	115
Lathe	115
Mortiser	115
Moulder	115
Planers	115
Power Trimmer & Mitre	115
Sanders	115
Saws	115
Shapers	115
Shingle Machine	115

CHAPTER VIII

Definitions

Adjustable Resistor—An adjustable resistor is a resistor so constructed that its resistance can be readily changed.*

Adjustohm†—A Vitrohm enameled resistor with a bare side and clamp for adjustment.

Alternating Current—An alternating current is a periodic current the average value of which over a period is zero. The equation for alternating current is the same as that for a periodic current except that $I_0 = O$*

Ambient Temperature — Ambient temperature is the temperature of the surrounding cooling medium, such as gas or liquid, which comes into contact with heated parts of the apparatus. *

Ampere—The ampere is the constant current which, maintained in two parallel rectilinear conductors of infinite length separated by a distance of 1 meter, produces between these conductors a force equal to 2×10^{-7} mks (meter-kilogram-second) units of force per meter of length.

Armature Resistor—A resistor connected in series with the armature of a motor either to limit the inrush current on starting, the gradual short circuiting of which brings the motor to normal speed, or to regulate the speed by armature-voltage control.

Axiohm†—A Vitrohm resistor with axial lead terminals.

Barohm† — Light-weight continuous-duty high-current resistor consisting basically of a channeled resistance alloy ribbon of uniform cross-section, formed in a series of flat turns secured at the middle of their short axes to specially treated asbestos-cement support board.

*ASA Standard
†Ward Leonard Trade Name

Bracket Terminal Resistors—Vitrohm resistors equipped with slotted metal end brackets that serve as a means of mounting and connecting to the resistor.

Capacitance—Capacitance is that property of a system of conductors and dielectrics which permits the storage of electricity when potential differences exist between the conductors. Its value is expressed as the ratio of a quantity of electricity to a potential difference. A capacitance value is always positive.*

Capacitor—A capacitor is a device, the primary purpose of which is to introduce capacitance into an electric circuit. Capacitors are usually classified, according to their dielectrics, as air capacitors, mica capacitors, paper capacitors, etc.*

Clearance—Clearance is the shortest distance through space between two live parts, between live parts and supports or other objects, or between any live part and grounded part.

Conduction—Conduction is the transmission of heat or electricity through, or by means of, a conductor.

Conductor—A conductor is a body so constructed from conducting material that it may be used as a carrier of electric current.*

Constant-Torque Resistor—A constant-torque resistor is a resistor for use in the armature or rotor circuit of a motor in which the current remains practically constant throughout the entire speed range.*

Continuous Duty—Continuous duty is a requirement of service that demands operation at a substantially constant load for an indefinitely long time.*

Continuous-Duty Resistor—A Continuous-duty resistor is one that is capable of carrying continuously the current for which it is designed without exceeding the specified temperature rise.

Continuous Rating—Continuous rating is the rating that defines the load which can be carried for an indefinitely long time.*

*ASA Standard

Definitions

Convection—Convection is the motion resulting in a fluid owing to differences of density and the action of gravity.

Creepage Distance—Creepage distance is the shortest distance between conductors of opposite polarity or between a live part and ground as measured over the surface of the supporting material.

Current-Limiting Resistor—A current-limiting resistor is a resistor inserted in an electric circuit to limit the flow of current to some predetermined value.

Note: A current-limiting resistor, usually in series with a fuse or circuit breaker, may be employed to limit the flow of circuit or system energy at the time of a fault or short-circuit.*

Dielectric Strength—The dielectric strength of an insulating material is the maximum potential gradient that the material can withstand without rupture.* It is usually specified in volts per unit thickness.

Dielectric Tests—Dielectric tests are tests which consist of the application of a voltage higher than the rated voltage for a specified time for the purpose of determining the adequacy against breakdown of insulating materials and spacings under normal conditions.*

Direct Current—A direct current is an unidirectional current in which the changes in value are either zero or so small that they may be neglected. A given current would be considered a direct current in some applications, but would not necessarily be so considered in other applications.*

Discohm†—Compact low-wattage non-inductive Vitrohm resistor having a flat circular ceramic base on which resistance wire is set and embedded in fused-on vitreous enamel.

*ASA Standard
†Ward Leonard Trade Name

Edgeohm†—High-current resistor made of an alloy resistance ribbon wound on edge forming an oval-shaped coil supported by grooved insulators which space adjacent turns and insulate them from the support bars. Support bars are secured to steel end pieces forming a sturdy resistor suitable for continuous-and-intermittent-duty applications.

EIA—EIA is the Electronic Industries Association.

Electromotive Force—The electromotive force is the agency causing the flow of current in a circuit. It is the electrical pressure (or drop) measured in volts.

Fan-Duty Resistor—A fan-duty resistor is a resistor for use in the armature or rotor circuit of a motor in which the current is approximately proportional to the speed of the motor.*

Farad—The farad is the capacitance of an electric condenser in which a charge of one coulomb produces a difference of potential of one volt between the poles of the capacitor.

Ferrule Resistor—Ferrule resistors are resistors supplied with ferrule terminals for mounting in standard fuse clips.

Field Discharge Switch—A switch usually of the knife blade type having auxiliary contacts for connecting the field of a generator or motor across a resistor (field discharge) at the instant preceding the opening of the switch.

Fixed Resistor—A fixed resistor is one designed to introduce only one set amount of resistance into an electrical circuit.

Henry—The henry is inductance of a closed circuit in which an electromotive force of 1 volt is produced when the electric current traversing the circuit varies uniformly at the rate of 1 ampere per second.

Hot Spot—The point or location of maximum temperature on the external surface of a resistor is the hot spot.

Hysterset†—Electronic method of control, including a special magnetic circuit, providing a high degree of power amplification especially adaptable for dimming purposes.

Inductance—Inductance is the (scalar) property of an electric circuit or of two neighboring circuits which determines the electromotive force induced in one of the circuits by a change of current in either of them.*

Impedance—The impedance of an electric circuit is the apparent resistance of an A.C. circuit, being the combination of both the resistance and reactance and is equal to the ratio of the value of the EMF between the terminals to the current, there being no source of power in the portion under consideration. The unit of impedance is the ohm and is represented by Z.

Intermittent Duty—Intermittent duty is a requirement of service that demands operation for alternate intervals of (1) load and no-load; or (2) load and rest; or (3) load, no-load and rest; such alternate intervals being definitely specified.*

Intermittent-Duty Resistor—An intermittent-duty resistor is one that is capable of carrying for a short period of time the high overload current for which it is designed without exceeding the specified temperature rise.

Loopohm†—High-current resistor having a resistance alloy ribbon of uniform cross-section formed in a series of loops supported between two steel rods insulated with ceramic washers and bushings. Rods are bolted to pressed steel frames providing a sturdy relatively light-weight continuous-duty resistor unit.

Machine-Duty Resistor—A machine-duty resistor is a resistor for use in the armature or rotor circuit of a motor in which the armature current is almost constant.

Megohm—A megohm is a unit of resistance and is equal to one million ohms.

MIL Resistors—MIL resistors are resistors built in accordance with Joint Army-Navy specifications.

Multi-Section Resistor—A multi-section resistor is a resistor having two or more electrically independent sections.

N.E.C.—The National Electrical Code is the standard of the National Board of Fire Underwriters for electric wiring and apparatus as recommended by the National Fire Protection Association and approved by the American Standards Association.

NEDA—NEDA is the National Electronic Distributors Association.

NEMA — NEMA is the National Electrical Manufacturers Association, a non-profit trade association, supported by the manufacturers of electrical apparatus and supplies. NEMA is engaged in standardization to facilitate understanding between the manufacturers and users of electrical products.

Nominal Diameter—Nominal diameter as applied to tubular Vitrohm resistors is the diameter of the ceramic tube expressed in inches and/or fractions thereof.

Nominal Length—Nominal length as applied to tubular Vitrohm resistors is the length of the resistor base or core expressed in inches and/or fractions thereof.

Non-Inductive Resistors—Non-inductive power resistors are those in which the inductance and distributed capacitance are reduced to an absolute minimum.

Ohm—The ohm is a unit of resistance and is defined as the resistance at 0°C of a column of mercury of uniform cross-section having a length of 106.3 centimeters and a mass of 14.4 grams.

Ohmmeter—An ohmmeter is an instrument for measuring electric resistance and is provided with a scale graduated in ohms.

Periodic Duty—Periodic duty is a type of intermittent duty in which the load conditions are regularly recurrent.*

Periodic Rating—The periodic rating defines the load which can be carried for the alternate periods of load and rest specified in the rating, the apparatus starting cold and for the total time specified in the rating without causing any of the specified limitations to be exceeded.*

Plaqohm†—An non-inductive Vitrohm resistor having a flat rectangular shaped molded ceramic base on which the resistive element is set and embedded with fused-on vitreous enamel.

Power—Power is the time rate of transferring or transforming energy; the rate of doing work or expending energy.

Power Resistors—Power resistors are resistors capable of dissipating 5 watts or more.

Rating—A rating of a machine, apparatus or device is a designated limit of operating characteristics based on definite conditions.

Note: 1—Such operating characteristics as load, voltage, frequency, etc., may be given in the rating.

Note: 2—The rating of control apparatus in general is expressed in volts, amperes, horsepower or kilowatts as may be appropriate, except that resistors are rated in ohms, amperes and class of service.*

Reactor—A reactor is a device used for introducing reactance into a circuit for purposes such as motor starting, paralleling transformers and control of current.*

Rectifier—A rectifier is a device which converts alternating current to unidirectional current by virtue of a characteristic permitting appreciable flow of current in only one direction. *

*ASA Standard
†Ward Leonard Trade Name

Resistance—Resistance is the (scalar) property of an electric circuit or of any body which may be used as part of an electric circuit which determines for a given current the rate at which electric energy is converted into heat or radiant energy and which has a value such that the product of the resistance and the square of the current gives the rate of conversion of energy. In the general case, resistance is a function of the current, but the term is most commonly used in connection with circuits where the resistance is independent of the current.*

Resistance Tolerance — The resistance tolerance of a power resistor is the extent to which its resistance may be permitted to deviate above or below the specified resistance. Resistance tolerance is usually expressed in percent.

Resistance Method of Temperature Determination — This method consists in the determination of temperature by comparison of the resistance of the winding at the temperature to be determined with the resistance at a known temperature.**

Resistive Conductor—A resistive conductor is a conductor used primarily because it possesses the property of high electric resistance.*

Resistivity—The resistivity of a material is the resistance of a sample of the material having specified dimensions.

Resistor—A resistor is a device, the primary purpose of which is to introduce resistance into an electric circuit.*

Resistor Core—The resistor core or base of a power resistor is the insulating support on which the resistive conductor is wound.

Rheostat—A rheostat is an adjustable resistor so constructed that its resistance may be changed without opening the circuit in which it may be connected.*

*ASA Standard
**NEMA Standard

Ribflex†—Tubular resistor consisting of an alloy resistance ribbon, crimped and edgewound on a ceramic core, the ribbon being securely and permanently fastened to the core by vitreous enamel.

Ribohm†—Resistor element made of a resistance alloy ribbon formed into a shallow channel shape and then formed into a vee, the ribbon being flat where the bends occur. Ends of the vee-shaped element are also flat and punched for securing the terminal assembly. Units are generally mounted on an impregnated asbestos composition faceplate.

RETMA—RETMA is the Radio-Electronics-Television Manufacturers Association. (See EIA.)

Screw-Base Resistors—Screw-base resistors are power-type Vitrohm resistors equipped with Edison-type screw-base terminals for quick interchangeability.

Short-Time Rating—The short-time rating is the rating that defines the load which can be carried for a short and definitely specified time, the machine, apparatus or device being at approximately room temperature at the time the load is applied.*

Single-Wound Resistor — A single-wound resistor is a resistor that has only one layer of resistance wire or ribbon wound around the insulating base or core.

Still Air—Still air is considered air having no circulation except that created by the heat of the resistor which is being operated.

Stock Resistors—Stock resistors are those popular size resistors available for immediate shipment.

Stripohm†—A Vitrohm resistor consisting of a hollow ceramic core, oval in shape, about which resistance wire is wound and completely embedded in vitreous enamel.

Tapped Resistor—A tapped resistor is one with two or more steps.

Temperature Coefficient of Resistance — The temperature coefficient of resistance is a measure of the

*ASA Standard
†Ward Leonard Trade Name

increase or decrease in resistance of a resistive conductor due to change in temperature.

Temperature Rise—Temperature rise is the difference in temperature between the initial and final temperature of a resistor. Temperature rise is expressed in degrees C or F, usually referred to an ambient temperature. Temperature rise equals the hot spot temperature minus the ambient temperature.

Thermal Shock—Thermal shock consists of a sudden marked change in the temperature of the medium in which the device operates.

Thermocouple—A thermocouple is a device for converting heat energy into electrical energy and is a pair of dissimilar conductors so joined as to produce a thermo-electric effect. It is used with a millivoltmeter to measure temperature rise in apparatus.

Thermometer Method of Temperature Determination—This method consists in the determination of the temperature by mercury or alcohol thermometers, by resistance thermometers, or by thermocouples, any of these instruments being applied to the hottest part of the apparatus accessible to mercury or alcohol thermometers.**

Varying Duty—Varying duty is a requirement of service that demands operation at loads, and for intervals of time, both of which may be subject to wide variation.*

Vitrohm†—Power-type vitreous enameled resistors, rheostats or resistance dimmers. A vitreous enamel developed by Ward Leonard.

Volt—The volt is a unit of electrical pressure, emf or potential difference. It is represented by E.

Watt—The watt is a unit of electric power. It is the power expended when one ampere of direct current flows through a resistor of one ohm.

Winding Pitch—Winding pitch is the distance from any point on a turn of a resistive conductor to the corresponding point on an adjacent turn measured parallel to the long axis of the winding.

*ASA Standard
**NEMA Standard
†Ward Leonard Trade Name

Useful Data

Conversion Factors

To find the unknown quantity (middle column) multiply the known value (left column) by the multiplier factor (right column)

Power

Known	Unknown	Multiplier Factor
Foot-pounds per min.	Horsepower	$.303 \times 10^{-4}$
Foot-pounds per min.	Watts	.0226
Foot-pounds per sec.	Horsepower	.001818
Foot-pounds per sec.	Watts	1.356
Horsepower	Foot-pounds per min.	33,000.
Horsepower	Foot-pounds per sec.	550.
Horsepower	Watts	746.
Kilog. m. per sec.	Watts	9.807
Watts	Foot-pounds per min.	44.25
Watts	Foot-pounds per sec.	.7375
Watts	Horsepower	.001341
Watts	Kilog. m. per sec.	.1020
Watts	B.T.U. per sec. (60°F)	.000948

Area

Known	Unknown	Multiplier Factor
Circular mils	Square inches	$.7854 \times 10^{-6}$
Circular mils	Square mils	.7854
Circular mils	Square millimeters	$.5066 \times 10^{-3}$
Square centimeters	Square inches	.155
Square feet	Square meters	.0929
Square inches	Circular mils	1,273,240
Square inches	Square centimeters	6.4516
Square inches	Square millimeters	645.16
Square inches	Square mils	10^{6}
Square meters	Square feet	10.764
Square millimeters	Square inches	.00155
Square millimeters	Circular mils	1,973.51
Square mils	Circular mils	1.2732
Square mils	Square inches	10^{-6}

Length

Known	Unknown	Multiplier Factor
Centimeters	Inches	.3937
Centimeters	Feet	.03281
Feet	Centimeters	30.48
Feet	Meters	.3048
Inches	Centimeters	2.54
Inches	Meters	.0254
Inches	Millimeters	25.4
Inches	Mils	1,000.
Kilometers	Miles	.6214
Meters	Feet	3.2808
Meters	Inches	39.3701
Meters	Yards	1.0936
Miles	Kilometers	1.6093
Millimeters	Inches	.03937
Millimeters	Mils	39.3701
Mils	Inches	.001
Mils	Millimeters	.0254
Yards	Meters	.9144

Energy

Known	Unknown	Multiplier Factor
B.T.U.	Foot-pounds	778.
B.T.U.	Joules	1055.
B.T.U.	Watt-hours	.293
Foot-pounds	B.T.U.	.001285
Foot-pounds	Joules	1.356
Foot-pounds	Kilogram-meters	.1383
Gram Calories	Joules	4.186
Joules	B.T.U.	.000947
Joules	Ergs	10^7
Joules	Foot-pounds	.7375
Joules	Gram-calories	.2388
Joules	Kilogram-meters	.10198
Kilogram-meters	Foot-pounds	7.233
Kilogram-meters	Joules	9.8047
Watt-hours	B.T.U.	3.4126

Useful Data

Miscellaneous

Known	Unknown	Multiplier Factor
Kilogram	Pounds	2.205
Kilog. per Kilom.	Pounds per 1000 ft.	6.719
Ohms per Kilom.	Ohms per 1000 ft.	.3048
Ohms per 1000 ft.	Ohms per Kilom.	3.2808
Ohms per 1000 yds.	Ohms per Kilom.	1.0936
Pounds	Kilograms	.4536
Pounds per 1000 ft.	Kilog. Kilom.	1.488
Pounds per 1000 yds.	Kilog. per Kilom.	.4960
Pounds per 1000 yds.	Pounds per Kilom.	1.0936
Resist. Microhm Cent.	Ohms/CMF	6.0153
Resist. in Ohms/CMF	Microhm Centimeters	.166

Drill Sizes For Machine Screws

Fractional Size Drills Inches	Wire Gauge and Letter Size Drills	Decimal Equivalent Inches	MACHINE SCREW				
			No.	O. D.	Threads Per Inch	Tap Drill	Clear. Drill
	80	.0135					
	79	.0145					
1/64		.0156					
	78	.0160					
	77	.0180					
	76	.0200					
	75	.0210					
	74	.0225					
	73	.0240					
	72	.0250					
	71	.0260					
	70	.0280					
	69	.0292					
	68	.0310					
1/32		.0312					
	67	.0320					
	66	.0330					
	65	.0350					
	64	.0360					
	63	.0370					
	62	.0380					
	61	.0390					
	60	.0400					
	59	.0410					
	58	.0420					
	57	.0430					
	56	.0465					
3/64		.0469					
	55	.0520					
	54	.0550					
	53	.0595					
1/16		.0625	0	.060	80	3/64	1/16
	52	.0635					
	51	.0670					
	50	.0700					
	49	.0730					
	48	.0760					
5/64		.0781					
	47	.0785	1	.078	72	53	47
	46	.0810			64	53	47
	45	.0820					
	44	.0860					
	43	.0890					
	42	.0935	2	.086	64	50	42
3/32		.0937			56	50	42
	41	.0960					
	40	.0980					
	39	.0995					
	38	.1015					
	37	.1040	3	.099	48	47	37
	36	.1065			56	45	37

Drill Sizes For Machine Screws (continued)

Fractional Size Drills Inches	Wire Gauge and Letter Size Drills	Decimal Equivalent Inches	MACHINE SCREW				
			No.	O. D.	Threads Per Inch	Tap Drill	Clear. Drill
7/64		.1094					
	35	.1100					
	34	.1110					
	33	.1130					
	32	.1160			36	44	31
	31	.1200	4	.112	40	43	31
1/8		.1250			48	42	31
	30	.1285					
	29	.1360	5	.125	40	38	29
	28	.1405			44	37	29
9/64		.1406			32	36	27
	27	.1440	6	.138	32	36	27
	26	.1470			40	33	27
	25	.1495					
	24	.1520					
	23	.1540					
5/32		.1562					
	22	.1570					
	21	.1590					
	20	.1610					
	19	.1660					
	18	.1695	8	.164	32	29	18
11/64		.1719			36	29	18
	17	.1730					
	16	.1770					
	15	.1800					
	14	.1820					
	13	.1850					
3/16		.1875					
	12	.1890					
	11	.1910					
	10	.1935					
	9	.1960	10	.190	24	25	9
	8	.1990			32	21	9
	7	.2010					
13/64		.2031					
	6	.2040					
	5	.2055					
	4	.2090					
	3	.2130					
7/32		.2187					
	2	.2210					
	1	.2280	12	.216	24	16	1
	A	.2340			28	14	1
15/64		.2344					
	B	.2380					
	C	.2420					
	D	.2460					
1/4	E	.2500					
	F	.2570					
	G	.2610					

Drill Sizes For Machine Screws (continued)

Fractional Size Drills Inches	Wire Gauge and Letter Size Drills	Decimal Equivalent Inches	MACHINE SCREW				
			No.	O. D.	Threads Per Inch	Tap Drill	Clear. Drill
17/64		.2656	1/4	.250	20	7	17/64
					28	3	17/64
	H	.2660					
	I	.2720					
	J	.2770					
	K	.2810					
9/32		.2812					
	L	.2900					
	M	.2950					
19/64		.2969					
	N	.3020					
5/16		.3125					
	O	.3160					
	P	.3230					
21/64		.3281	5/16	.3125	18	F	21/64
					24	I	21/64
	Q	.3320					
	R	.3390					
11/32		.3437					
	S	.3480					
	T	.3580					
23/64		.3594					
	U	.3680					
3/8		.3750					
	V	.3770					
	W	.3860					
25/64		.3906	3/8	.375	16	5/16	25/64
					24	Q	25/64
	X	.3970					
	Y	.4040					
13/32		.4062					
	Z	.4130					
27/64		.4219					
7/16		.4375					
29/64		.4531	7/16	.4515	14	U	29/64
					20	25/64	29/64
15/32		.4687					
31/64		.4844					
1/2		.5000					
33/64		.5156	1/2	.500	13	27/64	33/64
					20	29/64	33/64

Gauges for Wire, Sheet and Twist Drills

No. of Gauge	Washburn & Moen	American or Brown & Sharpe	Birmingham or Stubbs	U. S. standard for Plate (Iron & Steel)	Stubbs Steel Wire	Imperial Wire Gauge	Morse Twist Drill and Steel Wire	Wood and Machine Screws	American S. & W. Piano & Music Wire
7-0	......	......	......	.500	......	......	......	......	......
6-0	......	......	......	.469	......	.464	......	......	......
5-0	......	......	......	.438	......	.432	......	......	.005
4-0	.394	.460	.454	.406	......	.400	......	......	.006
3-0	.362	.410	.425	.375	......	.372	......	.032	.007
2-0	.331	.365	.380	.344	......	.348	......	.045	.008
0	.307	.325	.340	.313	......	.324	......	.058	.009
1	.283	.289	.300	.281	.227	.300	.228	.071	.010
2	.263	.258	.284	.266	.219	.276	.221	.084	.011
3	.244	.229	.259	.250	.212	.252	.213	.097	.012
4	.225	.204	.238	.234	.207	.232	.209	.110	.013
5	.207	.182	.220	.219	.204	.212	.206	.124	.014
6	.192	.162	.203	.203	.201	.192	.204	.137	.016
7	.177	.144	.180	.188	.199	.176	.201	.150	.018
8	.162	.128	.165	.172	.197	.160	.199	.163	.020
9	.148	.114	.148	.156	.194	.144	.196	.176	.022
10	.135	.102	.134	.141	.191	.128	.194	.189	.024
11	.120	.091	.120	.125	.188	.116	.191	.203	.026
12	.105	.081	.109	.109	.185	.104	.189	.216	.029
13	.092	.072	.095	.094	.182	.092	.185	.229	.031
14	.080	.064	.083	.078	.180	.080	.182	.242	.033
15	.072	.057	.072	.070	.178	.072	.180	.255	.035
16	.063	.051	.065	.063	.175	.064	.177	.268	.037
17	.054	.045	.058	.056	.172	.056	.173	.282	.039
18	.047	.040	.049	.050	.168	.048	.170	.295	.041
19	.041	.036	.042	.044	.164	.040	.166	.308	.043
20	.035	.032	.035	.038	.161	.036	.161	.321	.045
21	.032	.028	.032	.034	.157	.032	.159	.334	.047
22	.028	.025	.028	.031	.155	.028	.157	.347	.049
23	.025	.023	.025	.028	.153	.024	.154	.360	.051
24	.023	.020	.022	.025	.151	.022	.152	.374	.055
25	.020	.018	.020	.022	.148	.020	.150	.387	.059
26	.018	.016	.018	.019	.146	.018	.147	.400	.063
27	.0173	.0141	.016	.0171	.143	.0164	.144	.413	.067
28	.0162	.0126	.014	.0156	.139	.0149	.141	.426	.071
29	.015	.0112	.013	.014	.134	.0136	.136	.439	.075
30	.014	.010	.012	.0125	.127	.0124	.129	.453	.080
31	.0132	.0089	.010	.0109	.120	.0116	.120	.466	.085
32	.0128	.0079	.009	.0101	.115	.0108	.116	.479	.090
33	.0118	.007	.008	.0093	.112	.010	.113	.492	.095
34	.0104	.0063	.007	.0085	.110	.0092	.111	.505	.100
35	.0095	.0056	.005	.0078	.108	.0084	.110	.518	.106
36	.009	.005	.004	.007	.106	.0076	.1065	.532	.112
37	......	.0044	......	.0066	.103	.0068	.104	.545	.118
38	......	.0039	......	.0062	.101	.006	.1015	.558	.124
39	......	.0035	......	......	.099	.0052	.0995	.571	.130
40	......	.0031	......	......	.097	.0048	.098	.584	.138
41	......	......	......	......	.095	......	.096	.597	.146
42	......	......	......	......	.092	......	.094	.611	.154
43	......	......	......	......	.088	......	.089	.624	.162
44	......	......	......	......	.085	......	.086	.637	.170
45	......	......	......	......	.081	......	.082	.650	.180
46	......	......	......	......	.079	......	.081	.663	......
47	......	......	......	......	.077	......	.079	.676	......
48	......	......	......	......	.075	......	.076	.690	......
49	......	......	......	......	.072	......	.073	.703	......
50	......	......	......	......	.069	......	.070	.716	......

Electrical, Mechanical and Heat Equivalents

1 H. P.	1 Kw.	1 Watt
746 w.	1,000 w.	1 joule per sec.
0.746 kw.	1.34 hp.	0.00135 hp.
33,000 ft. lbs. per min.	2,655,750 ft. lbs. per hr.	3.412 btu. per hr.
550 ft. lbs. per sec.	44,263 ft. lbs. per min.	0.7377 ft. lbs. per sec.
2,544 btu. per hr.	737.7 ft. lbs. per sec.	0.0035 lb. water**
42.4 btu. per min.	3,413 btu. per hr.	44.26 ft. lbs. per min.
0.707 btu. per sec.	56.9 btu. per min.	
2.64 lbs. water*	0.948 btu. per sec.	
178 cal. gram per sec.	3.53 lbs. water*	

*Evaporated per hour from and at 212°F.
**Evaporated per hour.

1 H. P.-Hr.	1 Kw.-Hr.	1 Ft. Lb.
0.746 kw. hrs.	1,000 w. hrs.	1,356 joules
1,980,000 ft. lbs.	1.34 hp. hrs.	0.1383 kilog. m.
2,545 btu.	2,654,200 ft. lbs.	0.000000377 kw. hrs.
273,746 kilog. m.	3,600,000 joules	0.001285 btu.
2.62 lbs. water*	3,413 btu.	0.0000005 hp. hrs.
17.0 lbs. water**	367,000 kilog. m.	
	3.53 lbs. water*	
	22.75 lbs. water**	

*Evaporated from and at 212°F.
**Raised from 62° to 212°F.

Temperature Conversion Tables

Read the known temperature in the column marked with an asterisk. Corresponding temperature in degrees Centigrade will be found in the left hand column. The corresponding temperature in degrees Fahrenheit will be found in the right hand column.

0 to 39						40 to 79					
C.	*	F.	C.	*	F.	C.	*	F.	C.	*	F.
-17.8	0	32.0	- 6.67	20	68.0	4.44	40	104.0	15.6	60	140.0
-17.2	1	33.8	- 6.11	21	69.8	5.00	41	105.8	16.1	61	141.8
-16.7	2	35.6	- 5.56	22	71.6	5.56	42	107.6	16.7	62	143.6
-16.1	3	37.4	- 5.00	23	73.4	6.11	43	109.4	17.2	63	145.4
-15.6	4	39.2	- 4.44	24	75.2	6.67	44	111.2	17.8	64	147.2
-15.0	5	41.0	- 3.89	25	77.0	7.22	45	113.0	18.3	65	149.0
-14.4	6	42.8	- 3.33	26	78.8	7.78	46	114.8	18.9	66	150.8
-13.9	7	44.6	- 2.78	27	80.6	8.33	47	116.6	19.4	67	152.6
-13.3	8	46.4	- 2.22	28	82.4	8.89	48	118.4	20.0	68	154.4
-12.8	9	48.2	- 1.67	29	84.2	9.44	49	120.2	20.6	69	156.2
-12.2	10	50.0	- 1.11	30	86.0	10.0	50	122.0	21.1	70	158.0
-11.7	11	51.8	- 0.56	31	87.8	10.6	51	123.8	21.7	71	159.8
-11.1	12	53.6	0	32	89.6	11.1	52	125.6	22.2	72	161.6
-10.6	13	55.4	0.56	33	91.4	11.7	53	127.4	22.8	73	163.4
-10.0	14	57.2	1.11	34	93.2	12.2	54	129.2	23.3	74	165.2
- 9.44	15	59.0	1.67	35	95.0	12.8	55	131.0	23.9	75	167.0
- 8.89	16	60.8	2.22	36	96.8	13.3	56	132.8	24.4	76	168.8
- 8.33	17	62.6	2.78	37	98.6	13.9	57	134.6	25.0	77	170.6
- 7.78	18	64.4	3.33	38	100.4	14.4	58	136.4	25.6	78	172.4
- 7.22	19	66.2	3.89	39	102.2	15.0	59	138.2	26.1	79	174.2

Temperature Conversion Tables (continued)

80 to 740						750 to 1640					
C.	*	F.	C.	*	F.	C.	*	F.	C.	*	F.
26.7	80	176.0	171	340	644	399	750	1382	649	1200	2192
27.2	81	177.8	177	350	662	404	760	1400	654	1210	2210
27.8	82	179.6	182	360	680	410	770	1418	660	1220	2228
28.3	83	181.4	188	370	698	416	780	1436	666	1230	2246
28.9	84	183.2	193	380	716	421	790	1454	671	1240	2264
29.4	85	185.0	199	390	734	427	800	1472	677	1250	2282
30.0	86	186.8	204	400	752	432	810	1490	682	1260	2300
30.6	87	188.6	210	410	770	438	820	1508	688	1270	2318
31.1	88	190.4	216	420	788	443	830	1526	693	1280	2336
31.7	89	192.2	221	430	806	449	840	1544	699	1290	2354
32.2	90	194.0	227	440	824	454	850	1562	704	1300	2372
32.8	91	195.8	232	450	842	460	860	1580	710	1310	2390
33.3	92	197.6	238	460	860	466	870	1598	716	1320	2408
33.9	93	199.4	243	470	878	471	880	1616	721	1330	2426
34.4	94	201.2	249	480	896	477	890	1634	727	1340	2444
35.0	95	203.0	254	490	914	482	900	1652	732	1350	2462
35.6	96	204.8				488	910	1670	738	1360	2480
36.1	97	206.6				493	920	1688	743	1370	2498
36.7	98	208.4				499	930	1706	749	1380	2516
37.2	99	210.2				504	940	1724	754	1390	2534

38	100	212	260	500	932	510	950	1742	760	1400	2552
43	110	230	266	510	950	516	960	1760	766	1410	2570
49	120	248	271	520	968	521	970	1778	771	1420	2588
54	130	266	277	530	986	527	980	1796	777	1430	2606
60	140	284	282	540	1004	532	990	1814	782	1440	2624
66	150	302	288	550	1022	538	1000	1832	788	1450	2642
71	160	320	293	560	1040	543	1010	1850	793	1460	2660
77	170	338	299	570	1058	549	1020	1868	799	1470	2678
82	180	356	304	580	1076	554	1030	1886	804	1480	2696
88	190	374	310	590	1094	560	1040	1904	810	1490	2714
93	200	392	316	600	1112	566	1050	1922	816	1500	2732
99	210	410	321	610	1130	571	1060	1940	821	1510	2750
100	212	413	327	620	1148	577	1070	1958	827	1520	2768
104	220	428	332	630	1166	582	1080	1976	832	1530	2786
110	230	446	338	640	1184	588	1090	1994	838	1540	2804
116	240	464	343	650	1202	593	1100	2012	843	1550	2822
121	250	482	349	660	1220	599	1110	2030	849	1560	2840
127	260	500	354	670	1238	604	1120	2048	854	1570	2858
132	270	518	360	680	1256	610	1130	2066	860	1580	2876
138	280	536	366	690	1274	616	1140	2084	866	1590	2894
143	290	554	371	700	1292	621	1150	2102	871	1600	2912
149	300	572	377	710	1310	627	1160	2120	877	1610	2930
154	310	590	382	720	1328	632	1170	2138	882	1620	2948
160	320	608	388	730	1346	638	1180	2156	888	1630	2966
166	330	626	393	740	1364	643	1190	2174	893	1640	2984

Temperature Conversion Tables (continued)

1650 to 2340						2350 to 3000					
C.	*	F.	C.	*	F.	C.	*	F.	C.	*	F.
899	1650	3002	1093	2000	3632	1288	2350	4262	1482	2700	4892
904	1660	3020	1099	2010	3650	1293	2360	4280	1488	2710	4910
910	1670	3038	1104	2020	3668	1299	2370	4298	1493	2720	4928
916	1680	3056	1110	2030	3686	1304	2380	4316	1499	2730	4946
921	1690	3074	1116	2040	3704	1310	2390	4334	1504	2740	4964
927	1700	3092	1121	2050	3722	1316	2400	4352	1510	2750	4982
932	1710	3110	1127	2050	3740	1321	2410	4370	1516	2760	5000
938	1720	3128	1132	2070	3758	1327	2420	4388	1521	2770	5018
943	1730	3146	1138	2080	3776	1332	2430	4406	1527	2780	5036
949	1740	3164	1143	2090	3794	1338	2440	4424	1532	2790	5054
954	1750	3182	1149	2100	3812	1343	2450	4442	1538	2800	5072
960	1760	3200	1154	2110	3830	1349	2460	4460	1543	2810	5090
966	1770	3218	1160	2120	3848	1354	2470	4478	1549	2820	5108
971	1780	3236	1166	2130	3866	1360	2480	4496	1554	2830	5126
977	1790	3254	1171	2140	3884	1366	2490	4514	1560	2840	5144
982	1800	3272	1177	2150	3902	1371	2500	4532	1566	2850	5162
988	1810	3290	1182	2160	3920	1377	2510	4550	1571	2860	5180
993	1820	3308	1188	2170	3938	1382	2520	4568	1577	2870	5198
999	1830	3326	1193	2180	3956	1388	2530	4586	1582	2880	5216
1004	1840	3344	1199	2190	3974	1393	2540	4604	1588	2890	5234

1010	1850	3362	1204	2200	3992	1399	2550	4622	1593	2900	5252
1016	1860	3380	1210	2210	4010	1404	2560	4640	1599	2910	5270
1021	1870	3398	1216	2220	4028	1410	2570	4658	1604	2920	5288
1027	1880	3416	1221	2230	4046	1416	2580	4676	1610	2930	5306
1032	1890	3434	1227	2240	4064	1421	2590	4694	1616	2940	5324
1038	1900	3451	1232	2250	4082	1427	2600	4712	1621	2950	5342
1043	1910	3470	1238	2260	4100	1432	2610	4730	1627	2960	5360
1049	1920	3488	1243	2270	4118	1438	2620	4748	1632	2970	5378
1054	1930	3506	1249	2280	4136	1443	2630	4766	1638	2980	5396
1060	1940	3524	1254	2290	4154	1449	2640	4784	1643	2990	5414
1066	1950	3524	1260	2300	4172	1454	2650	4802	1649	3000	5432
1071	1960	3560	1266	2310	4190	1460	2660	4820			
1077	1970	3578	1271	2320	4208	1466	2670	4838			
1082	1980	3596	1277	2330	4226	1471	2680	4856			
1088	1990	3614	1282	2340	4244	1477	2690	4874			

INTERPOLATION VALUES FOR ABOVE TABLES

C°................	1	2	3	4	5
F°................	1.8	3.6	5.4	7.2	9.0
F°................	1	2	3	4	5
C°................	0.56	1.11	1.67	2.22	2.78

CONVERSION FORMULA

$C° = 5/9\ (F° - 32°)$ $F° = 9/5\ C° + 32°$

Full Load Motor Currents

All motor currents given below are approximate, based on average values as listed by the National Electrical Code. The table can be used for estimating purposes but is not intended for use in the selection of overload relays. As motor characteristics vary somewhat dependent on the particular manufacturer, variations of ±10% of the values listed below may be expected.

HP of Motor	FULL LOAD CURRENT IN AMPERES													
	A.C. Induction Type Motors, Squirrel Cage and Wound Rotor											D.C. Motors		
	*Single Phase			**Two-Phase (4 Wire)				***Three Phase						
	115-Volt	230-Volt	440-Volt	110-Volt	220-Volt	440-Volt	550-Volt	110-Volt	220-Volt	440-Volt	550-Volt	115-Volt	230-Volt	550-Volt
1/6	3.2	1.6												
¼	4.6	2.3												
½	7.4	3.7		4	2	1	.8	4	2	1	.8	4.6	2.3	
¾	10.2	5.1		4.8	2.4	1.2	1.0	5.6	2.8	1.4	1.1	6.6	3.3	1.4
1	13.	6.5		6.4	3.2	1.6	1.3	7	3.5	1.8	1.4	8.6	4.3	1.8
1½	18.4	9.2		8.8	4.4	2.2	1.8	10	5	2.5	2.0	12.6	6.3	2.6
2	24.	12.		11.2	5.6	2.8	2.2	13	6.5	3.3	2.6	16.4	8.2	3.4
3	34.	17.			8	4	3.2		9	4.5	4	24	12	5.0

5	56.	28.			13	7	6		15	7.5	6	40	20	8.3
7½	80.	40.	21.		19	9	8		22	11	9	58	29	12.0
10	100.	50.	26.		24	12	10		27	14	11	76.	38	16.0
15					34	17	14		40	20	16	112.	56	23.0
20					45	23	18		52	26	21	148	74	31.
25					55	28	22		64	32	26	184	92	38.
30					67	34	27		78	39	31	220	110	46.
40					88	44	35		104	52	41	292	146	61.
50					108	54	43		125	63	50	360	180	75.
60					129	65	52		150	75	60	430	215	90.
75					158	79	63		185	93	74	536	268	111.
100					212	106	85		246	123	98		355	148.
125					268	134	108		310	155	124		443	148.
150					311	155	124		360	180	144		534	220.
200					415	208	166		480	240	192		712	295.

*For full load current of 208 and 200 volts motors, increase corresponding 230-volt motor full load current by 10 and 15 percent respectively.

**On two-phase (4-wire) motors, the amperes carried by the common conductor is 1.41 times value given.

***For full load currents of 208 and 200 volt motors, increase the corresponding 220-volt motor full load current by 6 and 10 percent respectively.

MECHANICAL FUNCTIONS

Where k = elastic constant, m = mass, p = period of vibration, s = distance, t = time

Mean velocity, $V = \frac{s}{t}$

Instantaneous velocity, $v = \frac{ds}{dt}$

Acceleration, $a = \frac{v - v_0}{t} = \frac{dv}{dt}$

when $v_0 = 0$ $\quad v = at$

$s = \frac{1}{2} at^2$

Acceleration of gravity,

g = 32.16 ft. per sec. per sec.

g = 980.2 cm. per sec. per sec.

Centrifugal force $= \frac{mv^2}{r}$

where r = radius of path

Displacement of spring,

$s = Fk$

Force, $F = \frac{mv - mv_0}{t} = ma = m \frac{dv}{dt}$

Momentum = mv

Period of vibration, $p = 2\pi \sqrt{km}$

Power, $P = \frac{W}{t} = FV$

Weight (force of gravity) = mg

Work (energy), $W = Fs = mas = \frac{1}{2} mv^2$

ELECTRICAL ANALOGS

Where C = capacity, L = inductance, p = period of oscillation, Q = charge, t = time

Current, $I = \frac{Q}{t}$

$$i = \frac{dq}{dt}$$

Condenser charge, $Q = EC$

Electromotive force, $E = \frac{Li - Li_0}{t}$

$$e = L\frac{di}{dt}$$

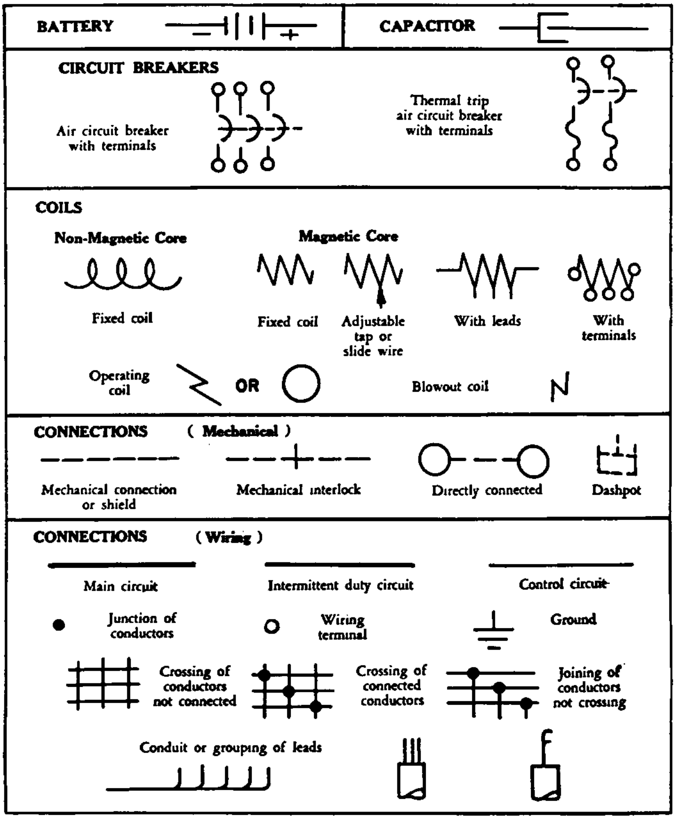
Period of oscillation, $p = 2\pi\sqrt{CL}$

$P = EI$

$W = EQ = EIt = \frac{1}{2}LI^2$

Symbols

For Power, Control and Measurement.



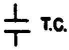
Useful Data

Symbols
For Power, Control and Measurement.

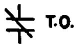
CONTACTS

Normally closed contact (N. C.)

Normally open contact (N. O.)

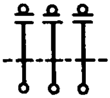


N. O. contact with time closing (T.C.) feature

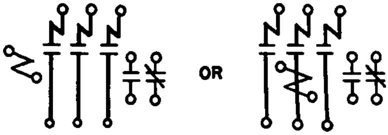


N. C. contact with time opening (T.O.) feature

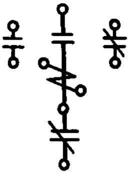
CONTACTORS



3-Pole manually operated contactor without B/O coils

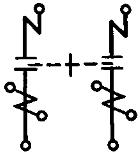


3-Pole electrically operated contactor with blowout coils and 1-N. O. and 1-N. C. auxiliary contacts

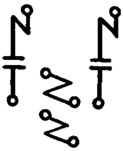


"Double-Throw" electrically operated contactor

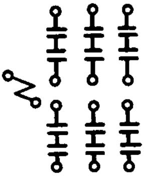
Single-Pole, electrically operated contactor—current lockout type



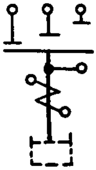
Two single-pole electrically operated contactors with mechanical interlock



2-Pole contactor with two operating coils



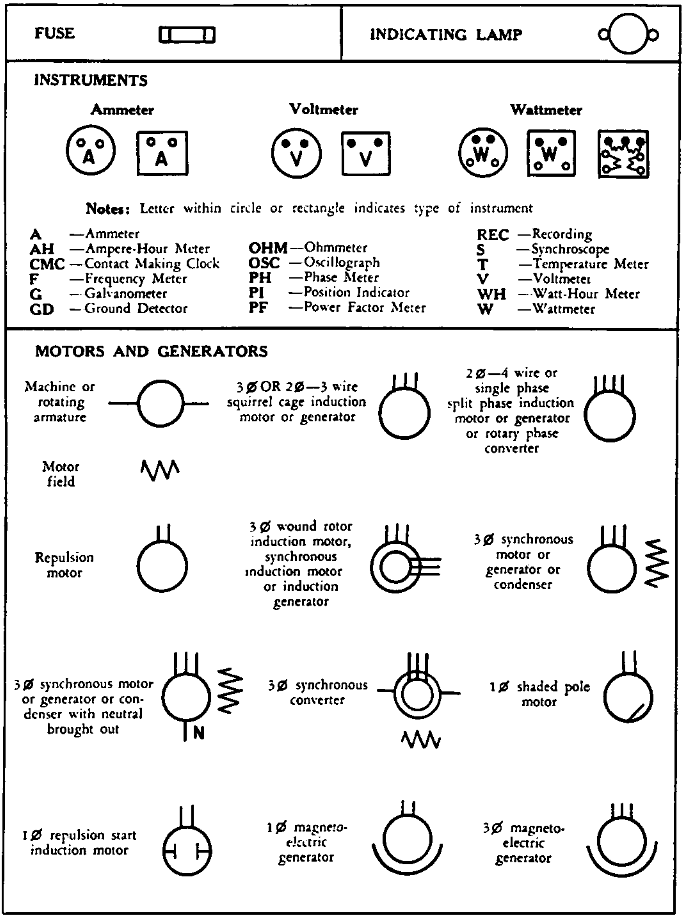
Three-Pole multi-break contactor



Time limit starter—dash-pot type

Symbols

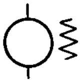
For Power, Control and Measurement.



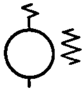
Symbols

For Power, Control and Measurement.

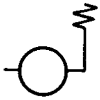
MOTORS AND GENERATORS (cont'd.)



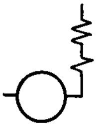
Separately excited D.C. generator or motor



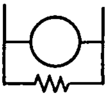
Separately excited D.C. generator or motor with commutating and/or compensating field winding



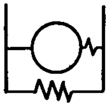
D.C. motor or 2-wire generator



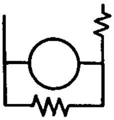
D.C. series motor or 2-wire generator with commutating and/or compensating field winding



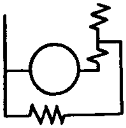
D.C. shunt motor or 2-wire generator



D.C. shunt motor or 2-wire generator with commutating and/or compensating field winding



D.C. compound motor or 2-wire generator or stabilized shunt motor

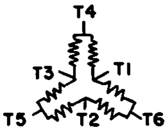


D.C. compound motor or 2-wire generator or stabilized shunt motor with commutating and/or compensating field winding

Symbols

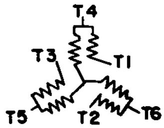
For Power, Control and Measurement.

MOTORS AND GENERATORS (cont'd)



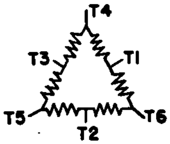
Constant-Torque 3ϕ Motor

Speed	Motor Connections to L1 L2 L3	Open	Shorted
Low	T1 T2 T3	T4, T5, T6	
High	T6 T4 T5		T1, T2, T3



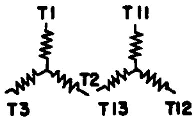
Variable-Torque $3\ \phi$ Motor

Speed	Motor Connections to L1 L2 L3	Open	Shorted
Low	T1 T2 T3	T4, T5, T6	
High	T6 T5 T4		T1, T2, T3



Constant Horsepower $3\ \phi$ Motor

Speed	Motor Connections to L1 L2 L3	Open	Shorted
Low	T1 T2 T3		T4, T5, T6
High	T6 T5 T4	T1, T2, T3	

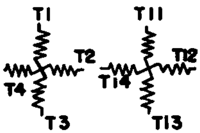


Separate Winding $3\ \phi$ Motor

Speed	Motor Connections to L1	L2	L3	Open
Low	T1	T2	T3	T11, 12, 13
High	T11	T12	T13	T1, 2, 3

Separate Winding $2\ \phi$ Motor

Speed	Motor Connections to L1	L2	L3	L4	Open
Low	T1	T2	T3	T4	T11, 12, 13, 14
High	T11	T12	T13	T14	T1, 2, 3, 4



Useful Data

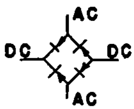
Symbols

For Power, Control and Measurement.

RECTIFIERS **Dry or electrolytic rectifier**

Half wave

OR

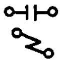


Full wave

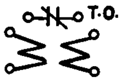
Rectifier

On complete diagrams rectifiers may be shown with terminals & polarity markings, heavy line may be used to indicate nameplate or positive polarity end.

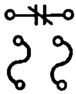
RELAYS



Overcurrent or overvoltage relay with 1—N. O. contact

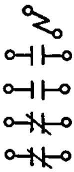


Magnetic overload relay having 2 current coils and 1—N.C. contact with timed opening (T.O.)

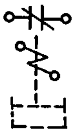


Thermal overload relay having 2 series heating elements & 1—N. C. contact

Thermal overload relay having 1 series heating element & 1—N. C. contact

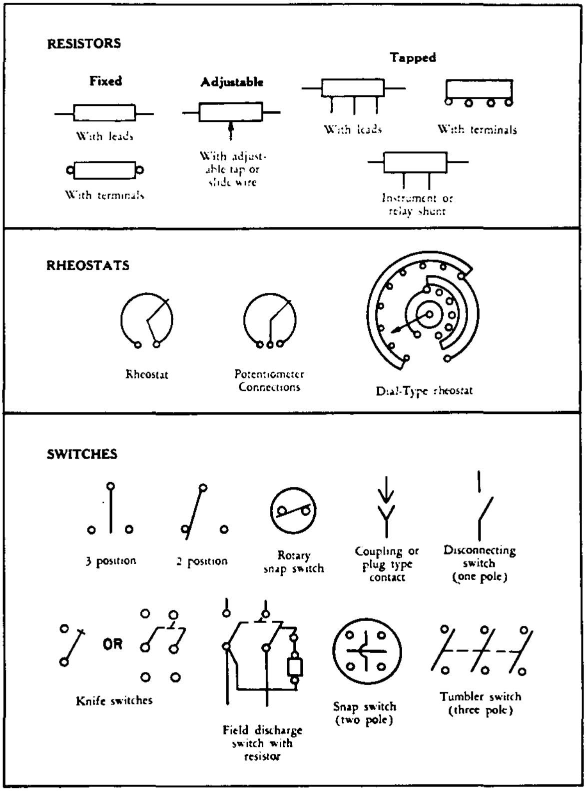


Multi-circuit relay with 2—N. O. & 2—N. C. contacts and operating coil



Magnetic overload relay having 1 series coil, 1—N. C. contact & dashpot

Symbols
For Power, Control and Measurement.

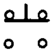


Symbols
For Power, Control and Measurement.

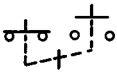
SWITCHES

Normally closed

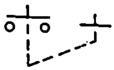
Normally open



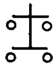
Push button open and closed (spring return)



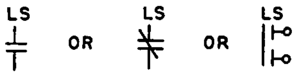
Push button open and closed (non-spring return)



Push button latch-in type for two wire control



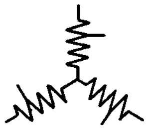
Push button double break



Limit switch contacts

TRANSFORMERS

Single phase two winding transformer



Special 3Ø WYE connected autotransformer with taps

Single phase two winding transformer with taps

Single phase autotransformer

Current transformer

BIBLIOGRAPHY AND REFERENCES

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1—American Society for Testing Materials—Metallic Materials for Electrical-Heating, Electrical Resistance and Electrical Contacts (with related information).
address: 1916 Race Street, Philadelphia 3, Pa.

2—National Electrical Code, Pamphlet No. 70, 1956.
address: National Fire Protection Association, 60 Batterymarch Street, Boston 10, Mass.

3—National Electrical Manufacturers Association Standards for Industrial Control, Pub. No. IC1,—May 1954
address: 155 East 44th Street, New York 17, N. Y.

4—Standard Handbook for Electrical Engineers, Knowlton, A. E., 8th Edition 1949, Pub. by McGraw-Hill Book Company, Inc.
address: 330 West 42nd Street, New York 17, N. Y.

5—Underwriters' Laboratories, Inc. Standard for Industrial Control Equipment, UL 508.
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Government Specifications

1—MIL-V-173 Military Specification—Coating-materials, moisture—and fungus resistant, for the treatment of communication, electronic, and associated electrical equipment.

2—MIL-D-3716 Military Specification—Dessicants (actuated).

3—MIL-R-11 Military Specification—Resistors, fixed composition (insulated).

4—MIL-R-19 Military Specification—Resistors variable wire-wound (low operating temperature).

5—MIL-R-22 Military Specification—Resistors variable (wire-wound power type).

Government Specifications (continued)

6—MIL-R-26 Military Specification. Resistors, fixed, wire-wound, power type.

7—JAN-R-29 Joint Army-Navy Specification—Resistors, external meter (high voltage, ferrule terminal type.)

8—MIL-R-93 Military Specification—Resistors, accurate, fixed, wire-wound.

9—MIL-R-94 National Military Establishment Specification—Resistors, variable, composition.

10—MIL-R-15109 (Ships) Military Specification—Resistors, and rheostats, shock proof (Naval Shipboard use).

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