SECTION IV

HEATING DATA

General

The primary heating considerations in the design of the coils for switching apparatus are: effects of temperature under normal operating conditions and effects of temperature under trouble conditions.

Normal heating is the condition imposed on the coil, with respect to the wattage and duration of energization, when the circuit in which the coil is used is functioning in a normal manner.

Trouble heating is the condition to which the coil is subjected when the circuit ceases to function normally. Trouble condition may result from a continuous application of voltage (which normally is applied intermittently), or from a short circuit, cross, or false ground that causes a higher voltage than normal to be impressed on the coil. It is assumed that any increase in temperature above the normal operating temperature limit, whether caused by circuit failures or by maintenance activity, constitutes trouble heating. It is not guaranteed that apparatus that has been subjected to a trouble condition will function satisfactorily thereafter. The coil, however, must withstand the trouble heating without creating a fire hazard. A coil meeting this trouble condition is said to be self-protecting.

Normal Operating Temperature Limits

Normal operating temperature limits are based on four factors:

1. The ability of the coil to withstand the operating temperature for extended periods of continuous or intermittent operation without impairment of the electrical performance throughout the life of the relay.

2. The ability of other parts of the structure, such as separators and insulators, to withstand the temperature imposed without the adjustment being affected adversely.

3. The possibility of injuries to personnel from bodily contact.

4. The possibility of contamination of apparatus and contacts by the volatile substances emitted.

A normal mean winding temperature limit of 225° F has been in effect since 1919; relays and switching apparatus generally have been designed to withstand an average operating temperature of the coil of 225° F. Since, under conditions of normal operation, all the foregoing considerations are controlling, the normal operating temperature limit was established irrespective of the type of wire insulation. In a few special cases, after consideration of the factors involved, temperatures in excess of 225° F have been permitted.

The normal heating is computed on the basis of the maximum initial watts and the maximum holding time per call, or the average holding time per busy hour, whichever is the greater.

Trouble Temperature Limits

The temperature of a magnet winding, placed across a battery, will rise by an amount depending on the values of the voltage and resistance and the heat dissipation characteristics of the magnet. The temperature of the winding will continue to rise until the point is reached where the power obtained from the battery is in equilibrium with the heat dissipated by the winding. The condition will stabilize at some elevated temperature provided this temperature is not high enough to cause a breakdown of the wire insulation. If this occurs, turns will become short-circuited, the magnet resistance will be lowered, more current will be drawn from the battery, and the temperature will rise further. Once started, the complete breakdown of the coil will proceed very rapidly, and during the period of disintegration, a very high temperature that may cause the magnet to become a fire hazard will be reached. Such a fire hazard can be avoided by insuring that the maximum temperature of the winding will never exceed that at which the wire insulation breaks down.

Various types of insulation have different heat-resisting properties, and these characteristics are controlling in the establishment of trouble temperature limits. The trouble temperature limits for a particular type of wire insulation were determined by energizing coils with various amounts of energy corresponding to predetermined winding temperatures. A coil failure was detected by measurements of the inductance at 1000 cycles. The inductance at such frequency shows a marked change with only a few short-circuited turns. Table IV-1 shows the temperature limits that have been established for the various wire insulations.

Indefinite and 48-Hour Trouble Heating Limits

When the trouble temperature limits were established in 1919, the limit for each type of insulated wire was set on the basis of the temperature that the coil would withstand satisfactorily for an indefinite period. In 1941, it was considered advisable to include in the limits the temperature at which coils with enameled wire might be expected to function for a limited period without becoming a fire hazard. Accordingly, a restricted temperature limit of 360° F, for cellulose-acetate-filled coils wound with thin-enameled wire per MS58364 was adopted. It was stipulated that this limit applied only where trouble conditions would not occur, or recur, for a cumulative total of more than 48 hours during the 40-year life of the relay. The 360° F temperature limit can be used only in circuit applications where it is feasible to administer the use of the coils to guarantee that trouble conditions would be detected within a very short time. Since a fire hazard might be involved in operating coils wound with MS58364 wire at 360° F for a cumulative time longer than 48 hours, the 250° F limit was retained for trouble heating periods of indefinite duration.

Maintenance Heating

It is a common practice, during installation and maintenance testing and trouble shooting, to block a circuit so that some relays are held energized for long periods of time. The heating under this condition should not exceed the normal limit if satisfactory performance is required subsequent to such maintenance activity. In a few special cases, such as the 270- and 400-ohm coils, where speed of operation is important, and after consideration of the factors involved, temperatures in excess of the normal limit have been permitted. While it is expected that no great risk is being taken with these two coils, based on experience with the 400-ohm U relay coil, it is not considered expedient to extend the maintenance heating limit above 225° F until more information has been obtained.

Intermittent Heating

With respect to the way they are used in circuits, relays may be divided into two general groups: those energized during conversation, and those energized as the call is being established.

The first group of relays has coils that must meet the normal heating limit when energized continuously.

The second group of relays is energized for times varying from fractions of a second to several seconds on a call and is then de-energized until the circuit is again seized on another call. The magnets are thus subjected to alternate periods of heating and cooling, generally called intermittent operation. With intermittent operation, the magnet temperature will rise during the heating, or "on" period, and drop during the cooling, or "off" period.

The percentage of the "on" period to the total period is called the percent time energized, or duty cycle. The ultimate coil temperature that will be attained is dependent on both the duty cycle and the total cycle. The duty cycle cannot always be applied, but approximate limits have been established for which the duty cycle may be applied. Tests have shown that for circuits like the marker, where the total cycle is approximately 1 second or for intervals up to 1 minute with equal "on" and "off" periods, the duty cycle may be applied.

The maximum temperature to which the coil will rise is not the temperature that the coil would attain if energized continuously with the same initial wattage; therefore, with intermittent operation, an initial wattage higher than that which would cause a rise in temperature to the normal limit of 225° F, with the magnet energized continuously, may be allowed.

The temperature rise, where the duty cycle is applicable, is based on a wattage equal to the initial wattage times the duty cycle. The allowable initial intermittent watts (W_I) is found from

$W_I = W_c \frac{a+b}{a}$ where W_c is the continuous watts, a is the "on" interval, and b the "off" interval. This method permits reasonably close results for short intervals in the order of 1 second with any duty cycle, or 1 minute with 15-percent duty cycle, but introduces a substantial error for 50-percent duty cycles in the order of 3 minutes.

Thermal Conductance

Most magnet coils are wound with copper wire which increases in resistance as its temperature is raised. Unless the energy supplied to the magnet is manipulated so as to remain constant as the temperature rises, there will be a change in energy consumption as the coil grows hotter. The temperature to which a magnet will rise bears a definite relationship to the electrical energy with which it is supplied. The quantity of heat which may be stored in a body is measured by its mass, its specific heat, and its increase in temperature.

Heat flows away from a coil principally through the core, by conduction, and through the outer surface of the coil by convection and radiation. The flow of thermal energy from a body resulting from its being at a higher temperature than its surroundings, and the energy lost by radiation to surrounding bodies depends on the thermal conductivity and dimensions of the body, and may be termed the thermal conductance.

The thermal conductance will depend on the conductivity of heat through the core, the area of the winding adjacent to the core, and the outside area of the coil. An empirical equation expressing this relationship is $\rho = \rho_a + \rho_c = K_a A_a + \frac{1}{R_{c1} + \frac{1}{K_c A_c}}$

where ρ = total thermal conductance

ρ_a = thermal conductance to the air

ρ_c = thermal conductance to the core

K_a = coefficient for conductance to the air

K_c = coefficient for conductance to the core

A_a = coil area exposed to the air

A_c = coil area adjacent to the core

R_{c1} = thermal resistance to the core

K is a coefficient expressed as the temperature rise that would result from supplying 1 watt per square inch of radiating area; it is assumed to be independent of the gauge and insulation of the wire, but varying with the area (A).

The thermal resistance is defined as the reciprocal of the thermal conductance, or $\frac{1}{\rho}$.

The values of ρ have been determined as part of the fundamental design of the wire spring relay. These values have been plotted in Fig. IV-1, which shows the thermal conductance for different winding depths, and Fig. IV-2, which shows the final temperature for different values of initial watts and thermal conductance.

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Allowable Heating

Since the thermal conductance increases with the winding depth, the allowable heating on a coil increases as the radiating area increases. The allowable initial wattage and thermal conductance for the AF, AG, and AJ relay coils are shown in Table IV-2. The wattage figures are valid only for coils wound with copper wire. The allowable initial wattage and thermal conductance for the AK relay are shown in Table IV-3.

The allowable initial watts for any AF, AG, or AJ relay coil may be computed by finding the thermal conductance for the particular coil from Fig. IV-1 for the winding depth of the coil. The depth of the coil may be found from data in Section X. From Fig. IV-2, the allowable initial watts may be found from the thermal conductance and temperature limit. The initial watts should be computed from the maximum voltage and minimum resistance.

Resistance Rise

The resistance of a coil wound with copper wire, subjected to a constant voltage, rises to some value higher than that obtained at ambient room temperature. This rise is computed from the minimum initial watts, ie, minimum circuit voltage and maximum coil resistance. If short holding times are involved, the initial watts may be multiplied by the duty cycle to obtain the equivalent initial watts. Knowing the initial watts and thermal conductance, the final temperature may be found in Fig. IV-2. The temperature coefficient for copper wire results in a rise of 1 percent for each 4.58° F increase in temperature. The hot resistance is therefore

$$R_H = R_{68}\left(1 + \frac{\text{final temperature} - 68°\ F}{458}\right).$$

To facilitate determining the hot resistance, the percent resistance rise has been plotted against the initial watts for different thermal constants in Fig. IV-3 and IV-4.

Resistance wire has a zero temperature coefficient and therefore does not increase in resistance due to heating.

Heating Conditions

The allowable wattage in Table IV-2 and the resistance rise in Fig. IV-3 and IV-4 are based on a constant voltage across the coil. Service conditions sometimes arise in which other than a constant voltage is used across a magnet. A list of these conditions, together with the formulae for determining the allowable watts and final temperature is shown in the appendix. Conditions not covered herein should be referred to the relay requirement group.

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Service conditions sometimes arise in which other than a constant voltage is used across a magnet. The conditions under which a magnet may be subjected to a temperature rise are:

1. Constant voltage.
2. Constant current condition. If the magnet is used in series with an external resistance of zero temperature coefficient, and the resistance of the magnet is a small part of the total circuit resistance, the current will not decrease materially as the magnet resistance increases due to the temperature rise.
3. Constant power. The circuit constants may change to maintain the wattage on the magnet constant.
4. Constant voltage with a copper winding in parallel with a resistance winding of zero temperature coefficient.
5. Constant voltage with a copper winding in series with a resistance winding of zero temperature coefficient.
6. Constant voltage with a copper winding in series with an external resistance of zero temperature coefficient.

Temperature formulae have been developed giving the maximum initial watts that will prevent an electromagnet from rising above given temperature limits. These formulae for conditions 1 to 6 above and the temperature limits are:

<u>Condition 1</u>

Initial watts $\left(\frac{E^2}{R_{68}}\right) = 168\ \rho\ (225°\ F)$

Initial watts $\left(\frac{E^2}{R_{68}}\right) = 210\ \rho\ (250°\ F)$

Initial watts $\left(\frac{E^2}{R_{68}}\right) = 426\ \rho\ (360°\ F)$

<u>Condition 2</u>

Initial watts $(I^2\ R_{68}) = 93.1\ \rho\ (225°\ F)$

Initial watts $(I^2\ R_{68}) = 107.3\ \rho\ (250°\ F)$

Initial watts $(I^2\ R_{68}) = 158.8\ \rho\ (360°\ F)$

<u>Condition 3</u>

Watts $= 125\ \rho\ (225°\ F)$

Watts $= 150\ \rho\ (250°\ F)$

Watts $= 260\ \rho\ (360°\ F)$

Condition 4

$$\frac{\text{Initial watts on cu wdg } \left(\frac{E^2}{R_{68}}\right)}{1.343} + \text{watts on res wdg } \left(\frac{E^2}{r}\right) = 125\ \rho \quad (225°\ F)$$

$$\frac{\text{Initial watts on cu wdg } \left(\frac{E^2}{R_{68}}\right)}{1.397} + \text{watts on res wdg } \left(\frac{E^2}{r}\right) = 150\ \rho \quad (250°\ F)$$

$$\frac{\text{Initial watts on cu wdg } \left(\frac{E^2}{R_{68}}\right)}{1.638} + \text{watts on res wdg } \left(\frac{E^2}{r}\right) = 260\ \rho \quad (360°\ F)$$

Condition 5

$$\frac{E^2}{1.343\ R_{68} + r} = 125\ \rho \quad (225°\ F)$$

$$\frac{E^2}{1.397\ R_{68} + r} = 150\ \rho \quad (250°\ F)$$

$$\frac{E^2}{1.638\ R_{68} + r} = 260\ \rho \quad (360°\ F)$$

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Condition 6

$$\text{Series res } (r) \text{ not less than } -1.343\ R_{68} + \sqrt{\frac{E^2\ R_{68}}{93.1\rho}} \quad (225°\ F)$$

$$\text{Series res } (r) \text{ not less than } -1.397\ R_{68} + \sqrt{\frac{E^2\ R_{68}}{107.3\rho}} \quad (250°\ F)$$

$$\text{Series res } (r) \text{ not less than } -1.638\ R_{68} + \sqrt{\frac{E^2\ R_{68}}{158.8\rho}} \quad (360°\ F)$$

The final temperature of a magnet for the different heating conditions listed previously may be calculated as shown below.

Condition 1

$$T = -145 + \sqrt{60{,}000 + \frac{458\ E^2}{R_{68}\rho}}$$

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Condition 2

$$T = \frac{490}{\frac{458\rho}{I^2 R_{68}} - 1} + 100$$

Condition 3

$$T = \frac{W}{\rho} + 100$$

Condition 5

$$T = -145 - \frac{229r}{R_{68}} + \frac{229}{R_{68}} \sqrt{(1.07\ R_{68} + r)^2 + \frac{E^2\ R_{68}}{114.5\rho}}$$

Heating conditions other than shown should be referred to the relay requirements group.

In the foregoing formulae:

E = Voltage in volts.

R_{68} = Resistance of the copper winding at 68° F.

r = Resistance of zero temperature coefficient winding.

ρ = Thermal conductance (from Fig. IV-1).

TABLE IV-1

RECOMMENDED TEMPERATURE LIMITS FOR ELECTROMAGNETS

CONCENTRIC WINDINGS, INCLUDING WINDINGS WITH SERIES TURNS OF RESISTANCE WIRES

	Mean Winding Temperature Limit for Trouble Conditions			
	Cellulose-Acetate-Filled Coils		Spoolwound Coils	
Insulation	Indefinite	48 Hours*	Indefinite	48 Hours*
Enamel per MS58364	250° F	360° F	Not Recommended	
Enamel per MS58364	250° F	360° F	250° F	325° F
Heavy Formex per MS58371	360° F		360° F	
Single Nylon per LRM-6034,1N1; Double Nylon per LRM-6034,1N2; Single Nylon Plus Enamel (LRM-6034,2N1); Double Nylon Plus Enamel (LRM-6034,2N2)	360° F		360° F	
Cotton or Cotton Plus Enamel	360° F		360° F	

Notes:

1. For coils in which freedom from short-circuited turns is essential, or where inductance requirements are specified, enameled wire per MS58371, or nylon insulated wires per LRM-6034, should be used.

2. Where series resistance wire is used, the turns should be spread over as much of the coil length as possible. The hot-spot temperature should not exceed the recommended maximum mean winding temperature for the type of insulation employed.

3. Coil temperatures are based on operation at 100° F ambient temperature.

* Coils should not be used in circuits where the cumulative hours of operation under trouble conditions may exceed 48 hours.

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PARALLEL, TWISTED, AND NONINDUCTIVE WINDINGS

Enameled wires, single nylon, or cotton should not be used. The insulation should be nylon per LRM-6034. Single cotton over MS58371 wire, or double cotton over MS58364, may also be used. The trouble temperature limits are the same as those for concentric windings.

Note: For all types of insulation and windings, the maximum mean winding temperature for normal operation should not exceed 225° F.

TABLE IV-2

HEATING LIMITS FOR AF, AG, AJ, AND AL RELAYS (Single-Wound Coils)

Res	Sleeve	Ther Cond	Allowable Wattage 225° F	250° F	360° F*
4.4		0.043	7.2	9.0	18.3
16		0.044	7.4	9.2	18.7
34		0.040	6.7	8.4	17.0
100		0.045	7.5	9.4	19.1
180		0.043	7.2	9.0	18.3
200		0.035	5.9	7.4	14.9
220	0.091 cu	0.033	5.6	7.0	14.1
270		0.048	8.0	10.0	20.6
275		0.043	7.2	9.0	18.3
395		0.043	7.2	9.0	18.3
400		0.033	5.6	7.0	14.1
500		0.040	6.7	8.4	17.0
550	0.147 cu	0.044	7.4	9.2	18.7
600	0.091 cu	0.044	7.4	9.2	18.7
700		0.026	4.4	5.5	11.1
800		0.041	6.9	8.7	17.5
860		0.034	5.7	7.2	14.5
875	0.046AL or cu	0.043	7.2	9.0	18.3
950		0.042	7.1	8.8	18.0
1000	0.147 cu	0.041	6.9	8.7	17.5
1050	0.147 cu	0.044	7.4	9.2	18.7
1625		0.043	7.2	9.0	18.3
2000	0.091	0.043	7.2	9.0	18.3
2200	0.046AL or cu	0.043	7.2	9.0	18.3
2500		0.043	7.2	9.0	18.3
2550	0.147 cu	0.041	6.9	8.7	17.5
3800		0.045	7.6	9.5	19.2
4000		0.045	7.6	9.5	19.2
6000		0.046	7.6	9.6	19.6
9100		0.043	7.2	9.0	18.3

TABLE IV-2a

HEATING LIMITS FOR AF, AG, AJ, AND AL RELAYS (Multiple-Wound Coils)

Res	Sleeve	Ther Cond	Allowable Wattage† 225° F	250° F	360° F*
P 2.7		0.041	6.9	8.7	17.5
S 690		0.043	7.2	9.0	18.3
P 8		0.041	6.9	8.7	17.5
S 850		0.043	7.2	9.0	18.3
P 10		0.036	6.1	7.6	15.3
S 400		0.040	6.7	8.4	17.0
P 16		0.034	5.7	7.2	14.4
S 16		0.038	6.4	8.0	16.2
P 61		0.042	7.1	8.8	18.0
S 61		0.037	6.2	7.8	15.8
P 100		0.043	7.2	9.0	18.3
S 100		0.039	6.6	8.2	16.6
P 100		0.033	5.6	7.0	14.1
S 1100		0.043	7.2	9.0	18.3

* 48-hour cumulative.
† Values listed should not be applied to winding simultaneously.

TABLE IV-2a (Cont)

HEATING LIMITS FOR AF, AG, AJ, AND AL RELAYS (Multiple-Wound Coils)

Res	Sleeve	Ther Cond	Allowable Wattage† 225° F	250° F	360° F*
P 170		0.033	5.6	7.0	14.1
S 140		0.043	7.2	9.0	18.3
P 198		0.034	5.7	7.2	14.5
S 90		0.041	6.9	8.7	17.5
P 200		0.044	7.4	9.2	18.7
S 200		0.040	6.7	8.4	17.0
P 210		0.036	6.1	7.6	15.4
S 1000		0.038	6.4	8.0	16.2
P 220		0.040	7.4	9.2	18.7
S 1150		0.043	7.2	9.0	18.3
P 300		0.034	5.7	7.2	14.5
S 300		0.040	6.7	8.4	17.0
P 335		0.039	6.6	8.2	16.6
S 335		0.036	6.1	7.6	15.3
P 360		0.034	5.7	7.2	14.5
S 1900		0.045	7.6	9.5	19.2
P 390		0.033	5.5	6.9	14.0
S 390		0.035	5.9	7.4	14.8
P 400		0.034	5.7	7.2	14.5
S 210		0.046	7.7	9.6	19.5
P 400		0.043	7.2	9.0	18.3
S 400		0.038	6.4	8.0	16.2
P 415		0.035	5.9	7.4	14.8
S 415		0.035	5.9	7.4	14.8
T 900		0.034	5.7	7.2	14.4
P 425		0.043	7.2	9.0	18.3
S 425		0.038	6.4	8.0	16.2
P 450		0.032	5.4	6.8	13.6
S 57		0.044	7.4	9.2	18.7
P 450		0.035	5.9	7.4	14.9
S 110		0.044	7.4	9.2	18.7
P 450		0.032	5.4	6.8	13.6
S 200		0.044	7.4	9.2	18.7
P 450	0.091 cu	0.038	6.4	8.0	16.2
S 500		0.045	7.6	9.5	19.2
P 540		0.033	5.6	7.0	14.1
P 540		0.036	6.1	7.6	15.3
P 550		0.033	5.6	7.0	14.1
S 550		0.037	6.2	7.8	15.8
T 525		0.041	6.9	8.7	17.5
P 700		0.034	5.7	7.2	14.5
S 700		0.043	7.2	9.0	18.3
P 700		0.033	5.5	6.9	14.0
S 3300		0.042	7.0	8.8	17.8
P 800		0.040	6.7	8.4	17.0
S 880		0.035	5.9	7.4	14.8
P 1000		0.033	5.6	7.0	14.1
S 42		0.045	7.6	9.5	19.2
P 1000		0.034	5.7	7.2	14.5
S 2700		0.043	7.2	9.0	18.3

* 48-hour cumulative.
† Values listed should not be applied to windings simultaneously.

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TABLE IV-2a (Cont)

HEATING LIMITS FOR AF, AG, AJ, AND AL RELAYS (Multiple-Wound Coils)

Res	Sleeve	Ther Cond	Allowable Wattage† 225° F	250° F	360° F*
P 1175		0.034	5.7	7.2	14.5
S 1075		0.043	7.2	9.0	18.3
P 1200		0.032	5.4	6.8	13.6
S 6000		0.045	7.6	9.5	19.2
P 1500		0.035	5.9	7.4	14.9
S 2950		0.044	7.4	9.2	18.7
P 1800		0.034	5.7	7.2	14.5
S 85		0.044	7.4	9.2	18.7
P 5000		0.040	6.7	8.4	17.0
S 1000		0.044	7.4	9.2	18.7

* 48-hour cumulative.
† Values listed should not be applied to windings simultaneously.

TABLE IV-3

HEATING LIMITS FOR AK AND AM RELAYS

	Ther Cond	Allowable Wattage 225° F	250° F	360° F*
One Coil Energized	0.031	5.1	6.5	13.2
Two Coils Energized	0.026	4.4†	5.5†	11.0†

* 48-hour cumulative
† Each Coil

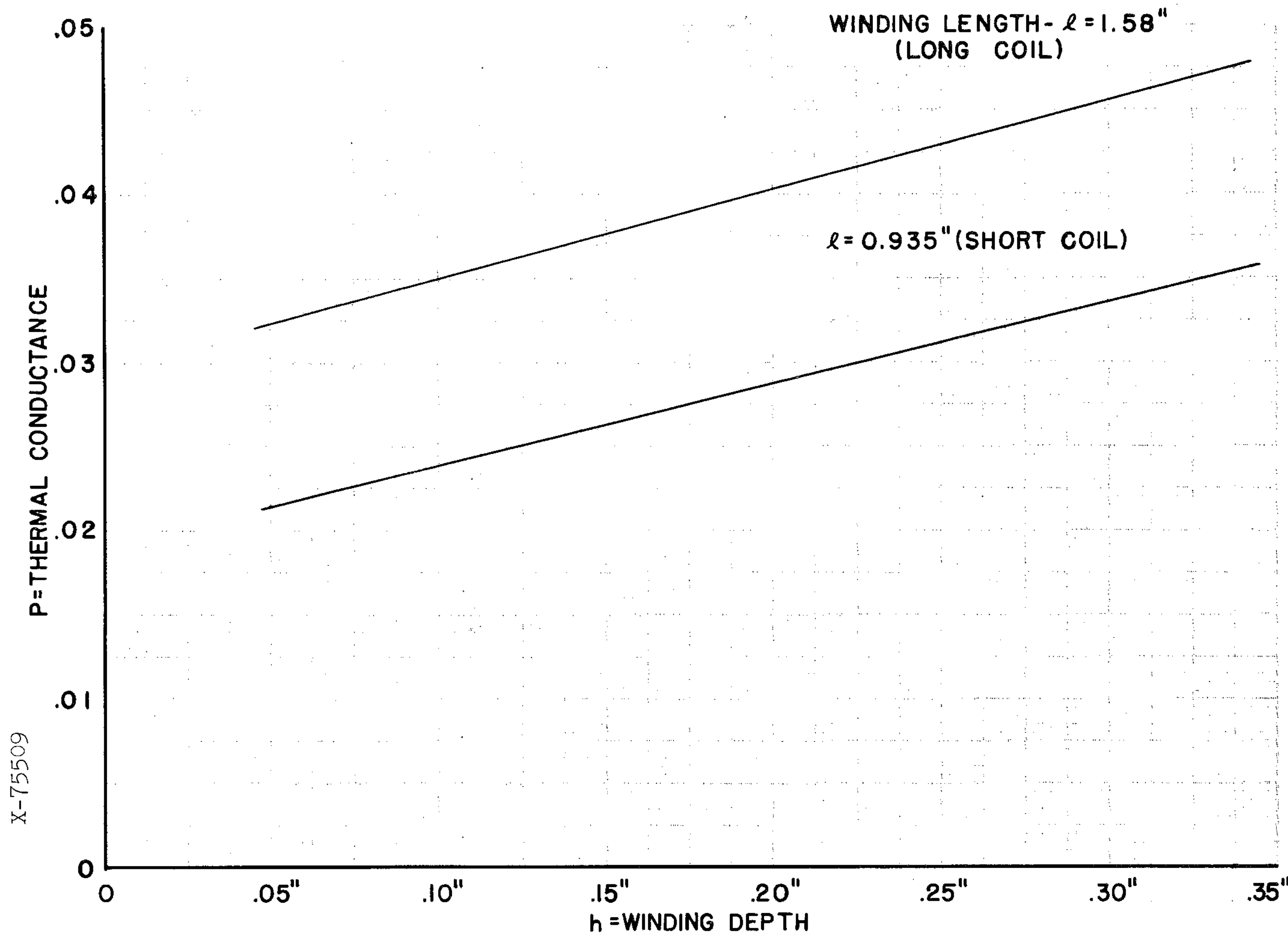

Fig. IV-1 - Thermal Conductance (ρ) for Various Winding Depths - AF, AG, and AJ Relays

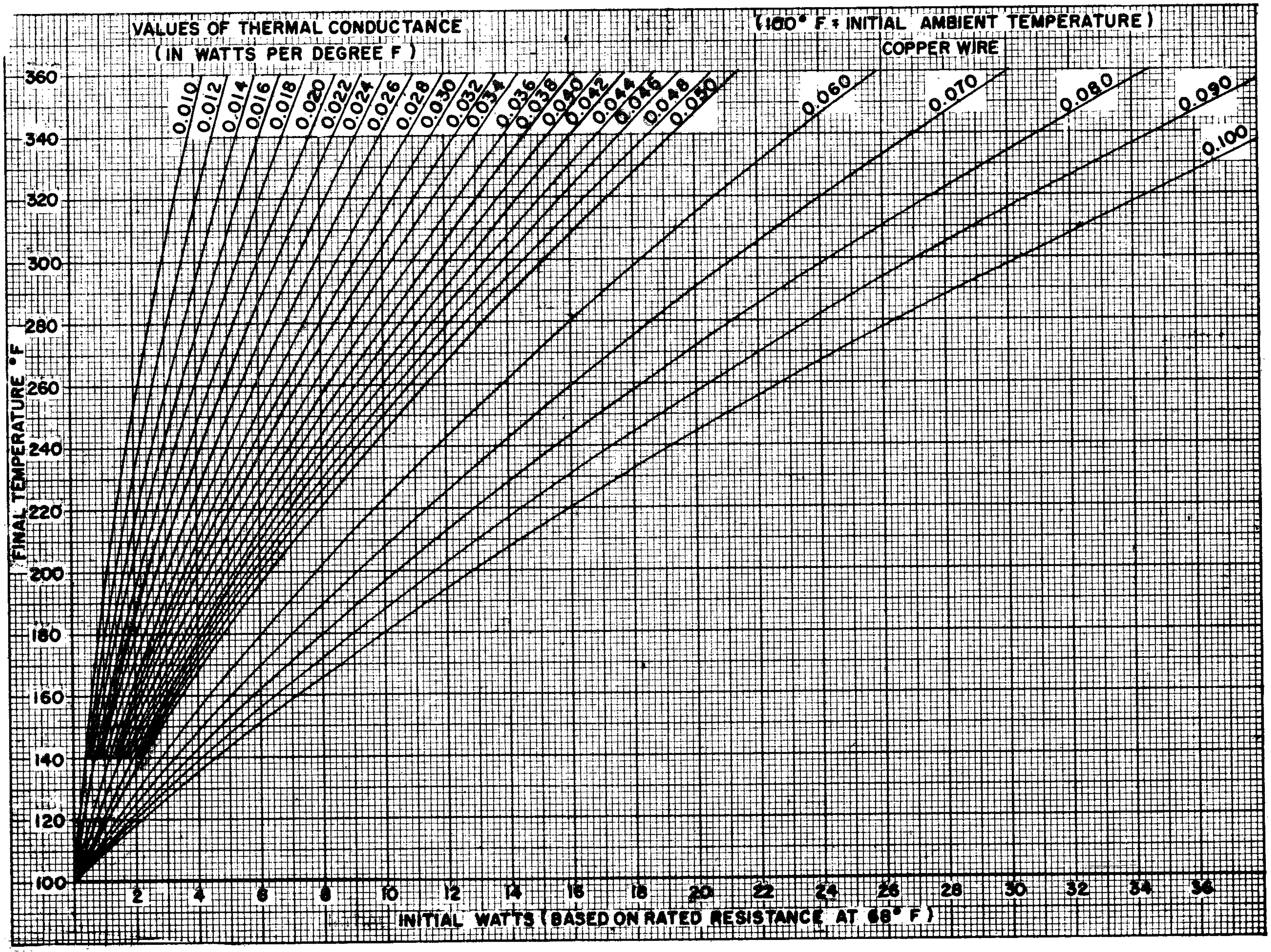

Fig. IV-2 - Constant Voltage Condition - Relation Between Initial Watts and Final Temperature

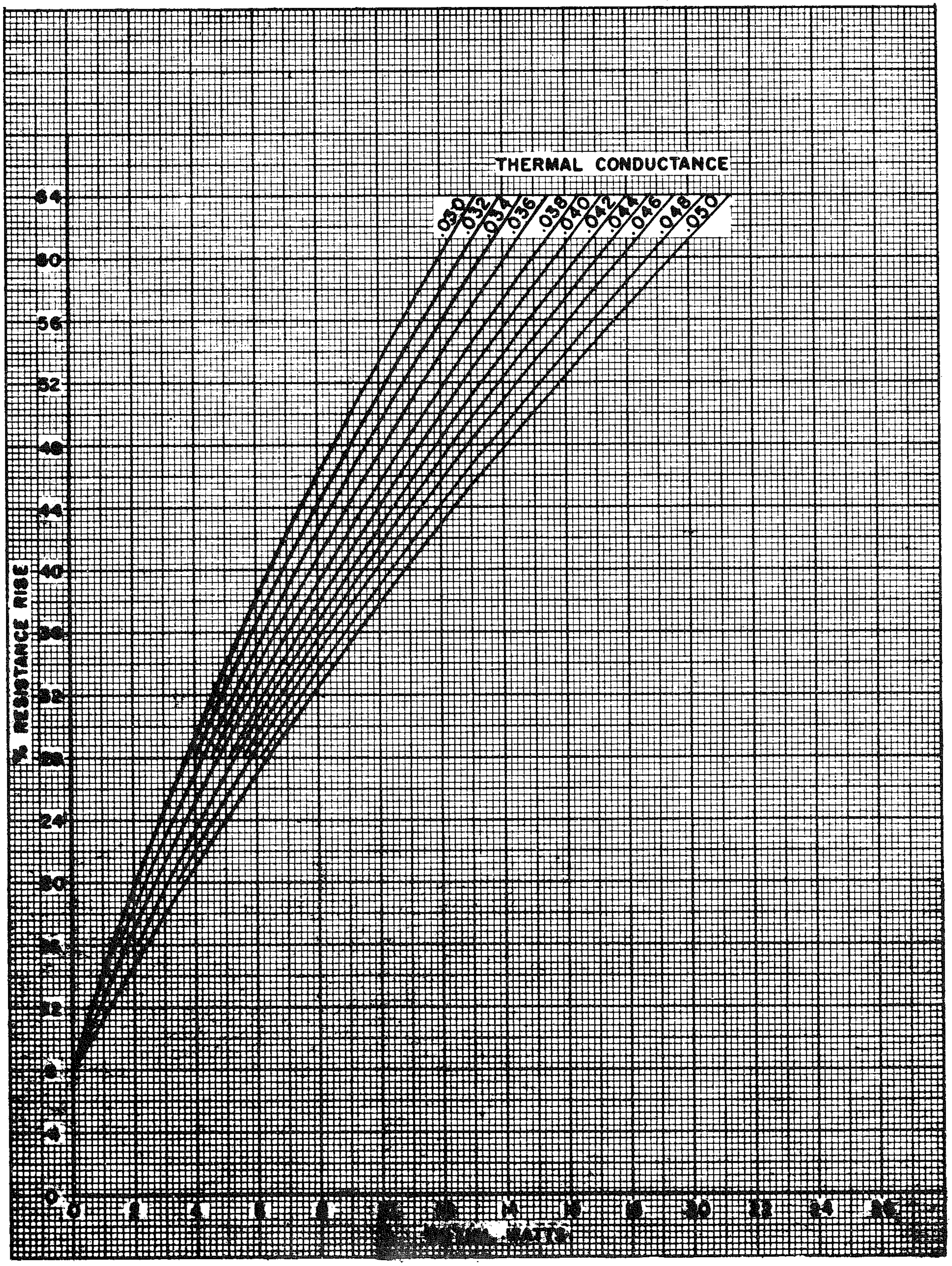

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Fig. IV-3 - Resistance Rise

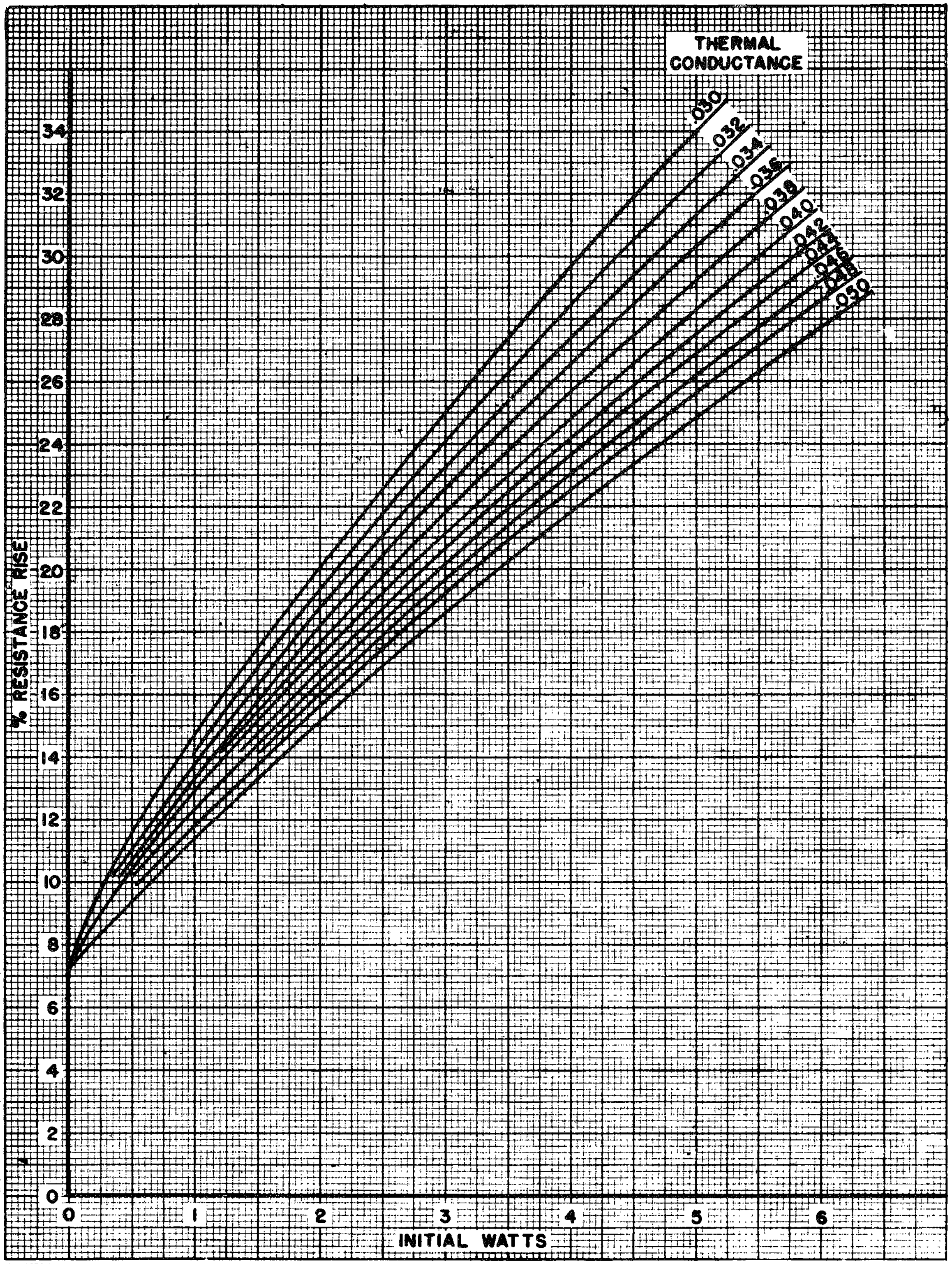

Fig. IV-4 - Resistance Rise