COILS

General

The wire spring relays use the cellulose-acetate-filled coil. This construction introduces a sheet of thin cellulose acetate between each layer of wire.

The multiple winding machine used in the manufacture of the filled coils employs round mandrels up to 15-3/4 inches long, on which are wound sticks of eight to twelve individual coils per mandrel. Wire is wound simultaneously from supply spools through wire guides spaced uniformly along the length of the mandrel. The coils are spaced 3/16 inch apart to provide insulation at the ends of the coils and space to permit cutting the stick into individual self-supporting coils.

During the winding operation, as the mandrel rotates, the winding mechanism moves along the mandrel and reverses direction at the completion of each layer of wire. As a layer is completed, and before the next one is wound, a sheet of cellulose interleaving is automatically cut to the required length and injected into the winding to cover the completed layer. In this manner, the layers of wire are interleaved with cellulose acetate.

When the required number of layers have been wound, a cellulose acetate cover is applied over the stick. The stick is then removed from the machine, the mandrel is withdrawn, and the coils are shaped to fit the rectangular wire spring relay core. The stick is cut into individual coils by means of a rotary multiple saw. Fig. X-1 shows the construction of the filled coil.

Normally, the interleaving is 0.0007 inch thick, but for wire sizes from 24 through 28, interleaving 0.002 inch thick is used in order to obtain a better bond to the spoolhead and to improve insulating the coil and leadout wires. Also, coils using wire

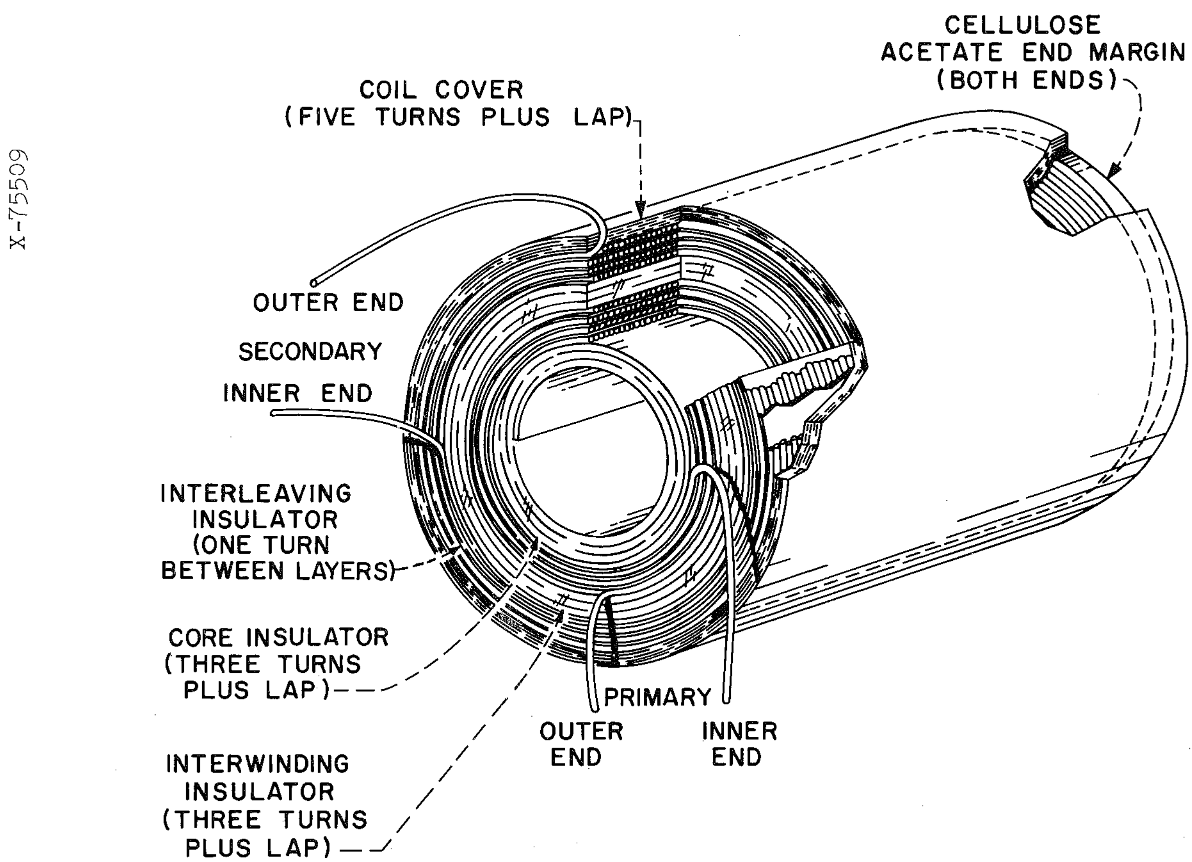
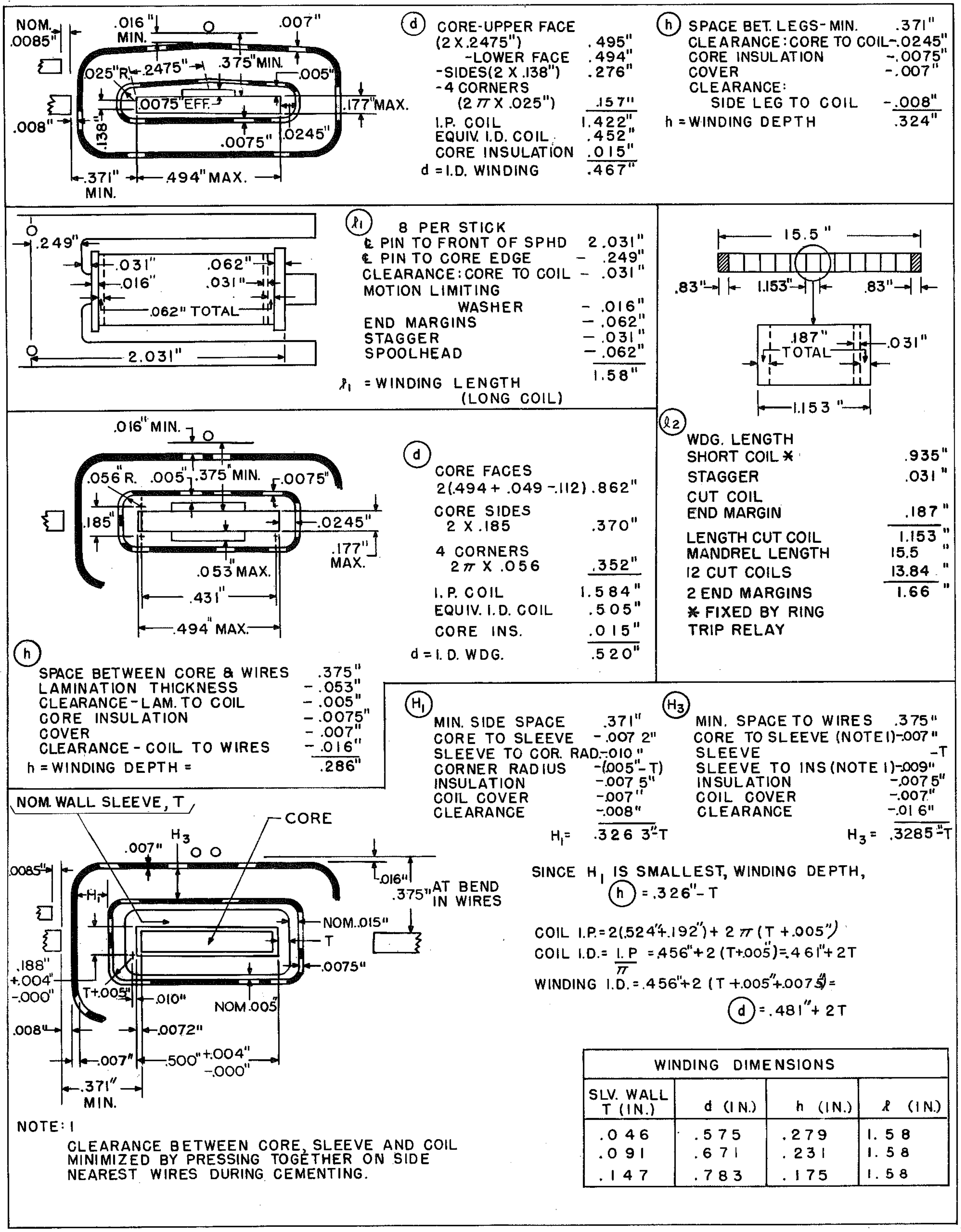


Fig. X-1 - Construction of a Cellulose-Acetate-Filled Coil



WINDING DIMENSIONS

SLV. WALL T (IN.)	d (IN.)	h (IN.)	ℓ (IN.)
.046	.575	.279	1.58
.091	.671	.231	1.58
.147	.783	.175	1.58

Fig. X-2 - AF, AG, and AJ Relays - Coil Dimensions gauges finer than 28 may use the 0.002-inch interleaving to increase the coil fullness and improve the thermal conductance or heat dissipation characteristic.

Secondary windings are wound over the primary windings before the shaping process, and the two windings together are then shaped to fit the rectangular core. Primary windings for relays with laminations or sleeves are wound on round arbors, with an equivalent diameter based on the circumference of the outer side of the laminations or sleeve, and then shaped to fit over the lamination or sleeve.

While noninductive windings may be wound on the wire spring relays, the use of these windings is not recommended as a general practice due to the added cost penalty imposed on the coil, especially for uses that do not require the extra resistance.

Filled coils are generally wound with enamel-covered wire per MS58364. This is a wire that is passed through the coating bath four times, resulting in a thinner enamel-coated wire than that used on spool-wound coils, which is passed through the coating bath eight times. Coils wound with 27 or heavier gauge wire should use MS58371 (heavy insulation) to protect against short-circuited turns caused by breaks in the MS58364 insulation during the shaping operation. The coils must meet a 500-volt ac breakdown test between the winding and any part of the frame. Spool-wound coils, which do not have the benefit of interleaving between adjacent layers of wire, must use wire with a heavier enamel coating than MS58364.

X-75509 In the process of assemblying the relay structure, the coil is first coalesced by holding the ends against a hot plate to seal the end of the coil and to adjust the length. A motion-limiting washer is slipped on the center leg of the core, followed by the coil and the front spoolhead. The leadout wires are threaded through the eyelets in the front spoolhead. The front spoolhead is pressed into position where it is held by a tight fit over a knurled portion of the core. The motion-limiting washer is held against the rear end of the coil, and this end is dipped into acetone to bond the washer to the coil. The coil is then pressed up against the front spoolhead and the front end of the coil dipped in acetone to bond the spoolhead to the coil. The leadout wires are soldered to the eyelets to complete the assembly.

The AF and AJ relays may be provided with either a long (full length) or a short coil, the short coil providing a reduction in winding cost where such coils will meet the circuit operating conditions. The short coils can be wound twelve at a time as contrasted with eight for a long coil. The AG relays are normally used where the full winding space is desired to obtain slow action; therefore, the short coil will not be used on the AG relay.

Available Coils

In the past, certain coils were preferred in order to minimize the number of coils. This practice has been discontinued because of improved manufacturing techniques, although the cost of a particular coil should remain a factor in its selection. In a few cases, however, it will not be possible to use an available coil due to the resistance limits imposed by connecting circuits and marginal or speed conditions. Special coils will be designed for these conditions when warranted. Table X-1 lists the coils that have been provided to date.

Winding Dimensions

The method of computing the winding dimensions is shown in Fig. X-2, and a photograph of the core structure is shown in Fig. X-3. The winding dimensions, in inches, for the wire spring relay coils are:

Type of Coil	Winding Depth (h)	Inner Diameter (d)	Length(ℓ) Long Coil	Length(ℓ) Short Coil
		AF, AG, and AJ Relays		
General Use	0.324	0.467	1.58	0.935
Laminated Core	0.286	0.520	1.58	
0.046 Sleeve	0.279	0.575	1.58	
0.091 Sleeve	0.231	0.671	1.58	
0.147 Sleeve	0.195	0.783	1.58	
		AK Relays		
General Use	0.202	0.363	1.31	0.935
0.069 Sleeve	0.128	0.531	1.31	

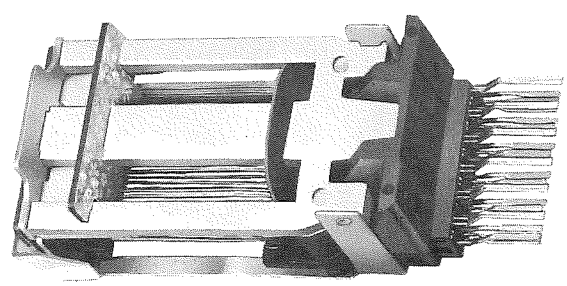


Fig. X-3 - Core Structure

Laminations and Sleeves

Laminated cores consist of a thin strip of metal, 0.050-inch thick and slightly narrower than the core, fastened to each side of the core. Laminations are used to obtain a high impedance for transmission circuits and to provide a better pull capability. Fig. X-4 shows the lamination used on each side of the core.

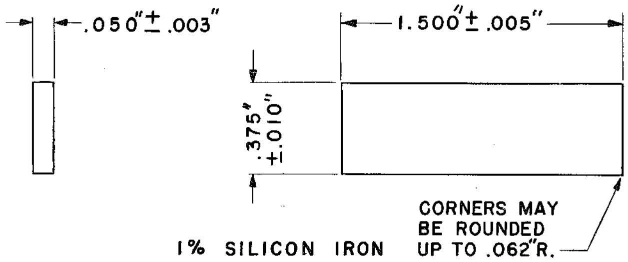
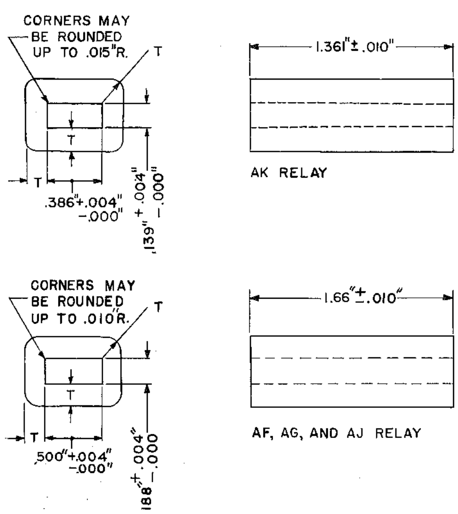


Fig. X-4 - Lamination

Copper or aluminum sleeves are provided on the wire spring relays to obtain slow operate or slow release times. The sleeves consist of seamless rectangular tubing with rounded outer corners and different wall thicknesses. The combination of metal and wall thickness is used to obtain different operating and releasing times. Fig. X-5 shows the dimensions of the various sleeves.



PIECE	DIM "T"	MATERIAL	USED ON
LP10A591	.0435"±.0035"	ALUMINUM	AF, AG, AJ RELAY
LP10A592	.0435"±.0035"	COPPER	AF, AG, AJ RELAY
LP10A593	.090"±.005"		
LP10A594	.145"±.006"		
LP10B988	.0695"±.005"	COPPER	AK RELAY

Fig. X-5 - Sleeve

Winding Arrangements

Arrangements are provided to bring out a maximum of six winding terminals on the AF, AG, AJ, and AL relays and three terminals on each half of the AK and AM relays. Fig. X-6 (parts 1, 2, and 3) shows the winding arrangements that have been used on the relays coded to date.

Coil Design

A coil design usually starts from one of three considerations:

1. Full-spool design for power saving or sensitivity.
2. A specific resistance required for a particular circuit condition.
3. Speed requirement.

The main difference in the design of coils to meet condition 1, 2, or 3 is the method of determining the number of layers and the size of the wire to be used. Once these factors have been determined, the design of a coil for any of the above conditions follows the same general method.

Full-Spool or Specific Resistance

A full-spool coil provides the best economic design for a relay with a long holding time. The first step is an estimate of the size of wire that should be used to provide a resistance of the desired value with a full spool. This estimate can be obtained from the curves shown in Fig. X-7 to X-10. These figures show the number of layers of any size wire required to provide a particular coil depth or resistance for different coil lengths and interleaving. These figures cannot be used directly for secondary windings or windings wound over laminations or sleeves.

Once the size of the wire has been chosen, the number of layers that may be wound on the spool must be determined. This may be obtained from Fig. X-7 to X-10, or may be determined as follows: No. of layers $(N_2) = \frac{h}{C_{max}}$ where h is the winding depth or radial space available for wire, in inches, and C_{max} is the maximum effective depth of one layer of wire and the interleaving, in inches. If the number of layers so calculated results in an odd number of layers, it must always be reduced to the next lower even number of layers. Tables X-2 and X-3 give the wire constants for thin enamel (MS 58364) wire for 0.0007-inch and 0.002-inch interleaving paper. Tables X-4 and X-5 give the wire constants for single and heavy formex wire with 0.002-inch interleaving paper.

Table X-6 lists the diameters over the insulation for the wires usually used in filled coil relays. The wire constants for filled coil design can be obtained from this table and the following relations:

$$B = 1.01\ g\ max$$

For 0.0007-inch interleaving paper:

$$C_{av} = 0.936\ (g_{av} + 0.00109)$$
$$C_{max} = 0.976\ (g_{max} + 0.00114)$$

For 0.0002-inch interleaving paper:

$$C_{av} = 0.978\ (g_{av} + 0.0026)$$
$$C_{max} = 1.010\ (g_{max} + 0.00317)$$

The maximum number of turns that may be wound on a layer is found from: turns per layer $(N_1) = \frac{\ell}{B}$ where ℓ is the length of the coil and B is the effective diameter of one turn of wire, in inches. The maximum number of turns is the product of the number of layers and the number of turns per layer. Some turns, however, will be lost in pulling out the leadout wires; by accidental breakages within the coil during winding (which could not be spliced until the machine was stopped); and by slight variations in the braking action as the winding machine is stopped. An allowance of 15 percent of one layer is allowed for these factors. The number of turns (N) that should be used for resistance calculations is therefore not more than the maximum number of turns that can be wound on the relay less 15 percent of one layer.

To simplify the withdrawal of the coil leadout wires after the coil has been cut from the stick, it is desirable that the winding should stop at the end of the coil rather than at any random point along the coil. All coils, therefore, should be wound to full layers, and to even numbers of layers so that all the wires will terminate at the same end of the coil.

Adjustments of the coil winding machine permit the pitch of the winding (turns per unit length of coil) to be set very accurately. This means that the maximum number of turns wound on a layer (100-percent pitch) can be reduced to permit adjusting the total turns to obtain an even number of full layers, or to adjust the resistance to the desired value by adjusting the total number of turns. The pitch is specified for the coil, and, for manufacturing reasons, should not be less than 85 percent.

The winding resistance is:

$$R = NA\left[N_2(C_{Av}) + d\right] \quad \text{where}$$

R = winding resistance ±10 percent

N = number of turns

A = a constant based on the resistivity of the wire

N_2 = number of layers

C_{Av} = average effective depth of one layer of wire

d = equivalent diameter of core (inner diameter) including any laminations, sleeves, or prior windings

The calculated resistance is specified to the nearest value as follows:

Calculated Resistance (ohms)	Specify to Nearest
10 - 20	0.2
21 - 50	0.5
51 - 100	1.0
101 - 200	2.0
201 - 500	5.0
501 - 1000	10.0
over - 1000	25.0

The number of turns (N), less one fifth of a layer allowance for stopping the machine and resistance adjustments, is rounded out in accordance with the following table:

Total Turns	Specify to Nearest
500 - 1000	5 turns
1001 - 5000	10 turns
5001 - 10000	25 turns
over - 10000	50 turns

These turns are specified as U (unlimited) turns. U turns are considered as varying one fifth of a layer from the specified number of turns.

The number of turns that should be wound on a layer are found from

$$N_1 = \frac{N}{N_2} \quad \text{where}$$

N_1 = the turns per layer

N_2 = the number of layers

N = the number of turns used in the resistance calculations rather than the specified number of turns.

Secondary windings are calculated the same as the primary windings, except that the diameter (d) is increased by twice the average depth of the primary winding. The insulation between the primary and secondary windings adds 0.012 inch to the depth of the primary winding. In computing coil fullness, the winding depth is based on the maximum depth of the primary winding plus the 0.012-inch insulation, plus the maximum depth of the secondary winding.

Slow releasing, or transmission relays, are designed like secondary windings on general purpose relays, except that it is not necessary to add the 0.012-inch interwinding insulation between the primary winding and the sleeve or laminations. Slow-releasing relays are normally designed to develop at least 300 ampere turns in order to saturate the core and provide the full releasing time.

Resistance Variation

The resistance variation is ordinarily ±10 percent. Single windings of 5 ohms or less vary ±15 percent and secondary windings wound over primary windings of less than 10 ohms vary ±15 percent. Relay windings can, in special cases, be held to

±5 percent. Where a ±5 percent resistance variation is to be specified, the winding resistance should be computed in the normal manner, the resistance increased 5 percent, and this value specified with a ±5 percent variation.

Fast Operate Coils

In the design of coils for fast operation, heating is an important consideration where circuit operating conditions do not limit the resistance; therefore, for the fastest operation, a relay should have the lowest coil resistance that will meet the heating requirements. The allowable temperatures and heating considerations are discussed more fully in Section IV, and only a reference to the method of using the heating data will be used herein.

The winding design starts with a determination of the probable resistance that will meet the heating requirements, considering the length of time that the relay will be energized. As an example of the method, assume the design of a fast-operating local-circuit relay for common use with a resistance of 400 ohms, and intermediate travel. Assume that the relay has a 50-percent duty cycle (see Section IV), ie, the operation is intermittent with the ratio of the on interval to the sum of the off and on intervals 0.5. For trouble condition, 100-percent duty, the maximum temperature should not exceed 250° F.

The extreme heating would result from the maximum voltage and minimum resistance. For maximum heating, the initial watts

$W_o = \frac{E^2}{R} = \frac{50^2}{360} = 6.95$. The relation between

the initial watts and the final temperature is shown in Fig. X-11. From this figure, a maximum temperature of 250° F with 6.95 initial watts requires that the thermal conductance (ρ) be 0.33 or greater, assuming no adjacent relays operated.

The winding depth is plotted against the thermal conductance in Fig. X-12 for various lengths of coils. From this figure, a thermal conductance of 0.033 requires a winding depth of 0.28 inch or more for the short coil (ℓ = 0.935 inch) but any winding depth over 0.06 inch is permissible for the long coil (ℓ = 1.58 inch).

The optimum number of turns to be used is that number of turns that, with a given resistance, will provide the least operate time for the relay spring load and armature travel. A greater number of turns will increase the initial inductance and the operating time. This is discussed more fully in Section VII covering operating times. Fast-operating relays should be designed as near the optimum number of turns as practical. The optimum turns are chosen using the nominal voltage and nominal hot operating resistance. For 50-percent duty cycle the nominal initial watts are:

$W_o = \frac{48^2}{400} = \frac{5.76}{2} = 2.88$ watts. From

Fig. X-11, with a thermal conductance of 0.033, the hot temperature will be 176° F.

The hot resistance is found by using

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

$$R_H = 400 \quad \left(1 + \frac{176-68}{458}\right) = 495$$

The optimum number of turns for a particular resistance is shown in Fig. X-13, and the effect on the operate time with a divergence from these turns is shown in Fig. X-14. From Fig. X-13, the optimum number of turns for a resistance of 495 ohms is 2800, assuming intermediate travel.

Fig. X-10 shows the number of layers of any size wire necessary to obtain a particular winding resistance for a given winding depth using 0.002-inch interleaving and a short coil. Fig. X-9 shows the same thing for 0.0007-inch interleaving. From Fig. X-10, 32 layers of 36E wire will provide a minimum winding depth of 0.25 inch and a resistance of approximately 400 ohms.

The number of turns of 36E wire that can be wound on a layer is

$N_1 = \frac{\ell}{B} = \frac{0.935}{0.00566} = 165$ turns. The total

number of turns for 32 layers would be 32 x 165 or 5300 turns, which is considerably above the optimum of 2800 turns. This means that the long coil is more advantageous since the short coil, to meet heating requirements, must have a winding depth that requires many more than the optimum number of turns.

From Fig. X-8 for the long coil with 0.002-inch interleaving, the smallest number of turns to provide 400 ohms is ten layers of 39E. This coil, using ten layers of 39E, computed as shown in the foregoing description of the design of a full-spool winding, would be the 3330 turns 39E, 400 ±10 percent.

With the coil design set, the actual performance data can be obtained. From Fig. X-8, ten layers of 39E give a winding depth of 0.06 inch. The thermal conductance, from Fig. X-12, is 0.033. With 6.95 initial watts, Fig. X-11 shows a final temperature of 246° F.

The minimum ampere turns are found as follows: The wattage developed would be

$\frac{45^2}{440} = 4.6$ watts for 100-percent duty or

2.3 watts for 50-percent duty. From Fig. X-11, with a thermal conductance of 0.033, and 2.3 watts, the final temperature is 158° F. The hot resistance

$R_H = 440 \left(1 + \frac{158-68}{458}\right) = 525$. The ampere turns are $\frac{45}{525} \cdot 3330 = 285$ NI. The actual method of computing the operating time is shown in Section VII.

Coil Cost

The coil cost can be compared using the cost per turn of winding the wire on the coil; the cost per ohm for the size of wire used; the cost of sleeves or laminations; and the cost of bringing out additional winding terminals. The cost for the coils used to date is shown in Table X-1. The method of computing the coil cost is shown in Section XI. The cost of power is also shown in Section XI.

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TABLE X-1

LIST OF COILS

AF, AG, AJ, AND AL RELAYS

Single-Wound Coils

Res	T/L	Turns	Wire Size	Coil Cost (cents)	Remarks
4.4	76	730	25E (MS58371)	14.5	0.002-inch interleaving. Fast operate in series with printer magnet. Resistance ±15 percent.
16	100	1580	27E (MS58371)	21.5	0.002-inch interleaving. Fast operate with 90 ohms. Must also operate in series with 525 ohms.
34	128	2260	29E	15.2	Marginal; tandem and toll trunks.
100	140	3900	31E	17.9	
180	177	5625	32E	18.6	Line relay to operate on high-voltage cross.
200	250	3950	35E	9.8	Fast operate on 24 volts.
270	212	2110	37E	18.1	0.002-inch interleaving. Fast operate; local circuit; intermittent heating. Epoxy resin-filled coil to meet heating conditions.
275	189	6700	33E	18.7	Required to operate in parallel with multicontact relay in marker double-connection check.
395	231	2670	40E	4.8	Fast operate; local circuit heating on 53.5 volts. Used where four relays are operated in parallel. Special for AMA center. 0.002-inch interleaving.
400	340	3330	39E	5.0	0.002-inch interleaving. Fast operate in local circuit where circuit conditions do not permit use of 27-ohm relay.
500	246	8275	35E	15.2	No. 1 switchboard sleeve relay with ±5 percent resistance. For use in other circuits with ±10 percent resistance.
700	190	5150	39E	5.5	Short coil 0.0007-inch interleaving. General use for fast operate.
800	277	10450	36E	16.3	PBX marginal sleeve condition.
860	392	6925	39E	7.5	Low wattage, fast operate coil.
950	270	11850	36E	18.9	To meet cross-detection requirements of series relay. Must work with existing relays.
1625	306	15800	37E	22.3	No sleeve; slow release obtained by external noninductive resistance shunt.
2500	335	19400	38E	22.6	General use. Low-current drain.
3800*	385	22200	39E	30.6	PBX marginal sleeve condition.
4000*	370	23600	39E	24.9	High resistance to limit current drain on rectifier of limited capacity.
6000	420	28000	40E	26.9	
9100*	474	34900	41E	31.1	Light spring loads in high-resistance circuit.

* These relays require the use of contact protection to limit the peak voltage to a safe value.

TABLE X-1 (Cont)

Slow-Acting Coils

	Res	T/L	Turns	Wire Size	Coil Cost (cents)	Remarks
	220	134	3710	34E	-	Short coil 0.091-inch copper sleeve; one iron and two copper washers. Ring trip relay.
Pri	220	225	4400	34E	26.6	0.046-inch copper sleeve. Ring-up relay.
Sec	1150	345	6775	38E		
	375	244	3850	36E	26.4	0.147-inch copper sleeve. Resistance ±5 percent. Must meet resistance limits of present pad control circuits.
Pri	450	279	4350	37E	19.7	0.091-inch copper sleeve. Slow release, double wound.
Sec	500	262	4600	36E		
	550	256	5575	36E	13.9	0.147-inch copper sleeve. Fast operate; slow release to hold over dial pulses.
	600	244	7800	35E	18.4	0.091-inch copper sleeve; fast saturation.
	875	265	10050	36E	17.7	0.046-inch aluminum sleeve.
	875	265	10050	36E	17.7	0.046-inch copper sleeve.
	1000	335	6450	38E	10.5	±5 percent resistance 0.147-inch copper sleeve. Limited by pad control circuit in No. 3C switchboard.
	1050	297	8250	37E	14.8	0.147-inch copper sleeve.
	2000	337	13500	38E	18.1	0.091-inch copper sleeve. Low-current drain; slow operate.
	2200	336	16050	38E	22.3	0.046-inch aluminum sleeve.
	2200	336	16050	38E	19.9	0.046-inch copper sleeve.
	2550	423	10080	40E	11.8	0.147-inch copper sleeve. Low-current drain.

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TABLE X-1 (Cont)

Double-Wound Coils

	Res	T/L	Turns	Wire Size	Coil Cost (cents)	Remarks
Pri	2.7	58	560	24E (MS58371)	20.4	0.002-inch interleaving on primary. Marker cross-detecting relay. Resistance ±15 percent.
Sec	690	391	3020	39E		
Pri	8	90	1050	26E (MS58371)	24.5	0.002-inch interleaving on primary. Marker cross-detecting relay. Secondary winding resistance ±15 percent.
Sec	850	391	3770	39E		
Pri	10	101	790	29E	19.4	0.002-inch interleaving on primary. Marker cross-detecting relay.
Sec	400	301	2950	38E		
Pri	16	130	1010	30E		0.0007-inch interleaving on primary. 0.002-inch interleaving on secondary.
Sec	16	114	1100	28E		
Pri	61*	189-139	2070	33E,31E	21.4	Limited turns. +15 -0 on pri A and pri B, +30 -0 on sec. Pri A and pri B connected in series. Battery feed on 24 volts.
Sec	61	177	2070	32E		
Pri	100*	184-164	2660	34E,32E	30.7	Limited turns. +15 -0 on pri A and pri B, +30 -0 on sec. Pri A and pri B connected in series. Battery feed on 24 volts.
Sec	100	194	2660	33E		
Pri	100	219	2590	34E	27.4	Differential marginal coil.
Sec	1100	303	9625	37E		
Pri	170	241	2800	36E	22.2	Fast operate on 20 volts.
Sec	140	178	3850	32E		
Pri	198	279	3250	36E	17.0	Fast operate, slow release with short-circuited secondary on 20 volts.
Sec	80	178	2430	32E		
Pri	200*	80-195	3235	36E,34E	20.6	Limited turns. +15 -0 on pri A and pri B, +30 -0 on sec Laminations on core. Pri A and pri B connected in series. Subscriber supervision and battery feed.
Sec	200	232	3235	35E		
Pri	210	231	4100	35E	23.5	
Sec	1000	301	8375	37E		
Pri	300	336	3250	38E	17.7	Fast operate. MS58371 single insulation.
Sec	300	269	3670	36E		
Pri	335*	348-340	3930	38E,36E	18.1	Limited turns. +15 -0 on pri A and pri B, +30 -0 on sec. Pri A and pri B connected ~~in~~ series. Balanced bridge relay for toll trunks.
Sec	335	283	3930	37E		
Pri	360	306	4800	37E	24.7	To work with existing relay in CAMA senders.
Sec	1900	348	13150	38E		
Pri	390	324	3170	39E		ESS No. 1 network control circuit. 0.002-inch interleaving.
Sec	390	265	3120	38E (MS58371)		
Pri	400	340	3330	39E	35.0	Register (RA) relay. 0.002-inch interleaving. Secondary winding ±3 percent resistance.
Sec	210	194	3440	33E		
Pri	400*	250-230	5200	37E,35E	26.9	Limited turns. +10 -0 on pri A and pri B, +20 -0 on sec. Pri A and pri B connected in series. Trunk supervision.
Sec	400	261	5200	36E		
Pri	415	310-269	4550	38TE,36TE	38.1	Limited turns. +15 -0 on pri A and pri B, +30 -0 on sec. Pri and sec winding resistance ±5 percent. Pri A and pri B connected in series. Trunk supervision.
Sec	415	285	4550	37TE		
Ter	900	335	5350	38TE		
Pri	425*	278-237	5520	37E,35E	28.0	Limited turns. +10 -0 on pri A and pri B, +20 -0 on sec. Pri A and pri B connected in series. Trunk Supervision.
Sec	425	277	5520	36E		

* Half of the primary wound under the secondary and half over the secondary

TABLE X-1 (Cont)

Double-Wound Coils

	Res	T/L	Turns	Wire Size	Coil Cost (cents)	Remarks
Pri	450	392	3000	40E	18.5	0.002-inch interleaving. Has function in trunk circuit similar to RA in register.
Sec	57	143	2540	40E		
Pri	450	389	3740	39E	39.3	Used in by-link trunks for function similar to register RA relay. 0.002-inch interleaving
Sec	110	178	3140	32E		
Pri	450	392	3000	40E	42.5	RA relay for panel and No. 1 crossbar. 0.002-inch interleaving. Secondary ±3 percent resistance.
Sec	200	176	3460	32E		
Pri	540	391	4550	39E	10.4	756 PBX line relay.
Sec	540	379	3730	39E		
Pri	550	369	3620	40E	19.9	0.002-inch interleaving. Marker class check relay.
Sec	550	369	3620	39E		
Ter	525	307	3620	38E		
Pri	700	325	7100	38E	23.3	Fast operate; short holding time.
Sec	700	277	7150	36E		
Pri	700	366	5750	39E	26.3	
Sec	3300	380	17400	39E		
Pri	800	267	9100	37E		Limited turns. +30 -0 on pri and sec. Pri and sec winding resistance ±5 percent.
Sec	880	297	5350	38E		
Pri	1000	417	6525	40E	21.6	Slow release, fast operate for ANI trunks.
Sec	42	128	2260	29E		
Pri	1000	366	7975	39E	24.0	Low drain.
Sec	2700	370	13950	39E		
Pri	1175	383	9125	39E	24.3	General use.
Sec	1075	306	9125	37E		
Pri	1200	425	7550	40E	53.3	Sleeve relay for CAMA trunk.
Sec	6000	426	19500	40E		
		1Sh	166	40ERW		
Pri	1500	434	9400	40E	26.3	Ring-up, lock-up relay.
Sec	2950	389	15400	39E		
Pri	1700	418	10300	40E	41.9	High resistance double-wound relay.
Sec	1700	337	11300	38E		
Pri	1800	425	11000	40E	23.2	No. 3C switchboard sleeve relay. Resistance ±5 percent.
Sec	85	156	2770	31E		
Pri	5000	475	22600	41E	28.1	Double-wound high resistance marginal relay.
Sec	1000	348	6140	38E		

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TABLE X-1a

LIST OF COILS
AK AND AM RELAYS

Single-Wound Coils

Res	T/L	Turns	Wire Size	Coil Cost (cents)	Remarks
5.5	74	725	222H		Resistance ±15 percent.
16	101	1390	29E		
65	148	2800	32E		
100	157	3400	33E	8.6	
145	186	4000	34E		
185	188	4820	34E	10.6	
210	226	4000	36E	7.4	
280	210	5825	35E	12.2	
410	234	6900	36E	10.6	
630	313	5000	40E		
640	255	8600	37E	11.7	
955	228	8125	39E	9.6	
960	289	10300	38E		
1500	310	12300	39E	11.2	
2450	360	15750	40E	14.3	

Double-Wound Coils

	Res	T/L	Turns	Wire Size
Pri	820	349	6282	40E
Sec	682	314	5024	39E

Coils With Copper Sleeve (0.069 inch)

Res	T/L	Turns	Wire Size	Coil Cost (cents)
315	221	4380	36E	10.6
680	286	6250	38E	
1100	320	7600	39E	

TABLE X-2

WINDING DESIGN TABLE FOR FILLED COILS
Thin Enameled Copper Wire (MS58364) - Standard 0.0007-Inch Interleaving (Preferred)

Wire Size AWG	For Max Turns and Fullness B (in.)	C Max (in.)	For Resistance and Wire Size A	C Avg (in.)	K (sq in.)	A/K	Copper Effi-ciency e	Wire Size AWG
29	0.0123	0.0130	0.0213	0.0122	0.000150	142	0.669	29
30	0.0110	0.0117	0.0272	0.0110	0.000121	225	0.649	30
31	0.00980	0.0105	0.0343	0.00983	0.0000963	356	0.646	31
32	0.00889	0.00970	0.0424	0.00902	0.0000802	529	0.627	32
33	0.00788	0.00873	0.0538	0.00809	0.0000637	845	0.622	33
34	0.00697	0.00785	0.0684	0.00729	0.0000508	1,350	0.614	34
35	0.00626	0.00716	0.0867	0.00664	0.0000416	2,080	0.591	35
36	0.00566	0.00658	0.109	0.00607	0.0000344	3,170	0.570	36
37	0.00515	0.00609	0.134	0.00561	0.0000289	4,640	0.550	37
38	0.00454	0.00550	0.169	0.00504	0.0000229	7,380	0.550	38
39	0.00404	0.00502	0.222	0.00458	0.0000185	12,000	0.519	39
40	0.00364	0.00463	0.284	0.00420	0.0000153	18,600	0.490	40
41	0.00333	0.00433	0.344	0.00392	0.0000130	26,500	0.477	41
42	0.00303	0.00404	0.435	0.00364	0.0000110	39,500	0.445	42

TABLE X-3

WINDING DESIGN TABLE FOR FILLED COILS
Thin Enameled Copper Wire (MS58364) - Special 0.002-Inch Interleaving

Wire* Size AWG	For Max Turns and Fullness B (in.)	C Max (in.)	For Resistance and Wire Size A	C Avg (in.)	K (sq in.)	A/K	Copper Effi-ciency e	Wire Size AWG
24	0.0231	0.0264	0.00672	0.0244	0.000564	11.9	0.572	24
25	0.0208	0.024	0.00848	0.0222	0.000462	18.3	0.544	25
26	0.0187	0.0219	0.0107	0.0201	0.000376	28.5	0.528	26
27	0.0167	0.0199	0.0135	0.0183	0.000305	44.2	0.519	27
28	0.0136	0.0168	0.0171	0.0155	0.000211	81	0.592	28
29	0.0123	0.0155	0.0213	0.0142	0.000175	122	0.574	29
30	0.0110	0.0142	0.0272	0.0130	0.000143	190	0.549	30
31	0.00980	0.0130	0.0343	0.0118	0.000116	296	0.536	31
32	0.00889	0.0121	0.0424	0.0110	0.0000978	434	0.514	32
33	0.00788	0.0111	0.0538	0.00998	0.0000787	684	0.503	33
34	0.00697	0.0102	0.0684	0.00914	0.0000637	1,070	0.490	34
35	0.00626	0.00946	0.0867	0.00845	0.0000529	1,640	0.465	35
36	0.00566	0.00886	0.109	0.00787	0.0000446	2,440	0.440	36
37	0.00515	0.00835	0.134	0.00738	0.0000380	3,520	0.419	37
38	0.00454	0.00775	0.169	0.00680	0.0000309	5,470	0.408	38
39	0.00404	0.00724	0.222	0.00630	0.0000254	8,740	0.378	39
40	0.00364	0.00684	0.284	0.00592	0.0000216	13,100	0.347	40
41	0.00333	0.00653	0.344	0.00562	0.0000187	18,400	0.332	41
42	0.00303	0.00623	0.435	0.00532	0.0000161	27,000	0.304	42

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* Wire gauges 24 to 27 inclusive use formex insulation (MS58371).

TABLE X-4

WINDING DESIGN TABLE FOR FILLED COILS
Single Formex Wire (MS58371) - 0.002-Inch Interleaving

Wire Size AWG	For Max Turns and Fullness B (in.)	C Max (in.)	For Resistance and Wire Size A	C Avg (in.)	K (sq in.)	A/K	Copper Effi ciency e	Wire Size AWG
24	0.0220	0.0258	0.0067	0.0241	0.000531	12.7	0.598	24
25	0.0197	0.0234	0.0085	0.0218	0.000429	19.8	0.586	25
26	0.0176	0.0211	0.0107	0.0197	0.000346	30.9	0.574	26
27	0.0158	0.0192	0.0135	0.0179	0.000283	47.7	0.559	27
28	0.0140	0.0174	0.0171	0.0162	0.000227	75.2	0.548	28
29	0.0127	0.0161	0.0213	0.0149	0.000189	112.9	0.531	29
30	0.0113	0.0146	0.0272	0.0134	0.000152	179.4	0.518	30
31	0.0102	0.0134	0.0343	0.0123	0.000125	273.5	0.496	31
32	0.0092	0.0124	0.0424	0.0113	0.000104	407.7	0.483	32
33	0.0083	0.0114	0.0538	0.0104	0.0000863	623.4	0.458	33
34	0.0074	0.0105	0.0684	0.0095	0.0000705	970.2	0.442	34
35	0.0066	0.0096	0.0867	0.0087	0.0000574	1,510.5	0.429	35
36	0.00596	0.00899	0.109	0.0081	0.0000482	2,261.4	0.407	36
37	0.0054	0.0084	0.134	0.0075	0.0000403	3,325.0	0.394	37
38	0.0048	0.0077	0.169	0.0069	0.0000328	5,152.0	0.383	38
39	0.0042	0.0072	0.222	0.0064	0.0000269	8,259.0	0.358	39
40	0.0038	0.0068	0.284	0.00599	0.0000228	12,456.0	0.331	40
41	0.0034	0.0064	0.344	0.0056	0.000019	18,134.0	0.324	41
42	0.0030	0.0059	0.435	0.0052	0.0000157	27,700.0	0.313	42

TABLE X-5

WINDING DESIGN TABLE FOR FILLED COILS
Heavy Formex Wire (MS58371) - 0.002-inch Interleaving

Wire Size AWG	For Max Turns and Fullness B (in.)	C Max (in.)	For Resistance and Wire Size A	C Avg (in.)	K (sq in.)	A/K	Copper Effi- ciency e	Wire Size AWG
24	0.0231	0.0269	0.0067	0.0252	0.00058	11.55	0.545	24
25	0.0208	0.0245	0.0085	0.0229	0.00048	17.85	0.530	25
26	0.0187	0.0223	0.0107	0.0207	0.000387	27.6	0.513	26
27	0.0167	0.0202	0.0135	0.0188	0.000314	42.99	0.504	27
28	0.0149	0.0184	0.0171	0.0171	0.000254	67.3	0.491	28
29	0.0135	0.0169	0.0213	0.0156	0.000211	101.1	0.476	29
30	0.0121	0.0154	0.0272	0.0142	0.000172	158.2	0.457	30
31	0.0109	0.0142	0.0343	0.013	0.000142	242.1	0.439	31
32	0.00999	0.0132	0.0424	0.012	0.00012	353.7	0.424	32
33	0.00889	0.0121	0.0538	0.011	0.0000974	552.4	0.417	33
34	0.0079	0.0110	0.0684	0.00999	0.0000789	866.9	0.395	24
25	0.0071	0.0102	0.0867	0.0092	0.000065	1,333.0	0.378	35
36	0.0062	0.0092	0.109	0.0084	0.0000518	2,105.5	0.364	36
37	0.0058	0.0088	0.134	0.0079	0.0000458	2,928.0	0.347	37
38	0.0052	0.0082	0.169	0.0073	0.0000378	4,470.0	0.332	38
39	0.0045	0.0075	0.222	0.0067	0.0000300	7,407.0	0.321	39
40	0.0040	0.007	0.284	0.0062	0.0000251	11,340.0	0.301	40
41	0.0036	0.0066	0.344	0.0058	0.0000208	16,540.0	0.296	41
42	0.0032	0.0062	0.435	0.0054	0.0000172	25,300.0	0.285	42

TABLE X-6

WIRE TABLE
DIAMETER OVER INSULATION (g) IN MIL INCHES

Wire Size	Thin Enamel (MS58364)			Single Formex			Heavy Formex			Enamel Nylon		
AWG	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max
20				32.7	33.4	34.1	33.9	34.6	35.3	34.3	35.4	36.5
21				29.2	29.9	30.6	30.3	31.0	31.7	30.7	31.75	32.8
22				26.0	26.65	27.3	27.0	27.7	28.4	27.4	28.45	29.5
23				23.3	23.85	24.4	24.3	24.9	25.5	24.7	25.65	26.6
24	20.4	20.8	21.2	20.8	21.3	21.8	21.8	22.35	22.9	22.1	23.05	24.0
25	18.2	18.6	19.0	18.6	19.05	19.5	19.5	20.05	20.6	19.9	20.8	21.7
26	16.1	16.5	16.9	16.5	16.95	17.4	17.4	17.95	18.5	17.8	18.7	19.6
27	14.5	14.8	15.1	14.9	15.25	15.6	15.7	16.10	16.5	16.2	16.95	17.7
28	12.9	13.2	13.5	13.2	13.55	13.9	14.0	14.4	14.8	14.6	15.3	16.0
29	11.6	11.9	12.2	11.9	12.25	12.6	12.6	13.0	13.4	13.2	13.9	14.6
30	10.3	10.6	10.9	10.5	10.85	11.2	11.2	11.6	12.0	11.9	12.6	13.3
31	9.2	9.45	9.7	9.4	9.75	10.1	10.1	10.45	10.8	10.7	11.4	12.1
32	8.3	8.55	8.8	8.5	8.8	9.1	9.1	9.45	9.8	9.8	10.5	11.2
33	7.3	7.55	7.8	7.6	7.9	8.2	8.1	8.45	8.8	8.8	9.5	10.2
34	6.5	6.7	6.9	6.8	7.05	7.3	7.2	7.5	7.8	8.0	8.7	9.4
35	5.8	6.0	6.2	6.0	6.25	6.5	6.4	6.7	7.0	7.2	7.9	8.6
36	5.2	5.4	5.6	5.4	5.65	5.9	5.7	6.0	6.3	6.6	7.3	8.0
37	4.7	4.9	5.1	4.9	5.1	5.3	5.2	5.45	5.7	6.0	6.7	7.4
38	4.1	4.3	4.5	4.3	4.5	4.7	4.6	4.85	5.1	5.5	6.2	6.9
39	3.6	3.8	4.0	3.8	4.0	4.2	4.0	4.25	4.5	4.9	5.6	6.3
40	3.2	3.4	3.6	3.4	3.6	3.8	3.6	3.8	4.0	4.5	5.2	5.9
41	2.9	3.1	3.3	3.0	3.2	3.4	3.2	3.4	3.6	4.1	4.8	5.5
42	2.6	2.8	3.0	2.6	2.8	3.0	2.8	3.0	3.2	3.8	4.5	5.2

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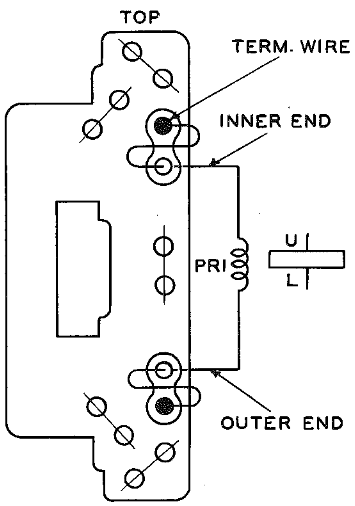

FIG. 1
SINGLE WINDING
SINGLE ARMATURE
TYPE

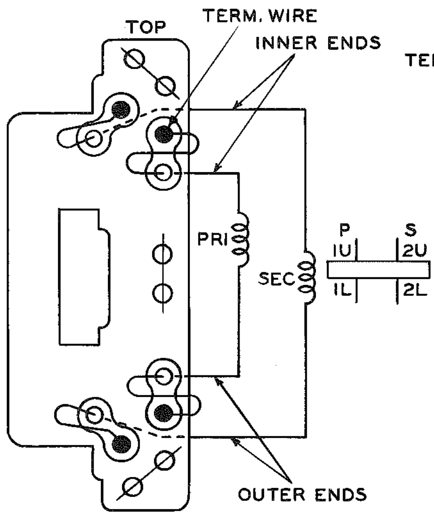

FIG. 2
DOUBLE WINDING
SINGLE ARMATURE
TYPE

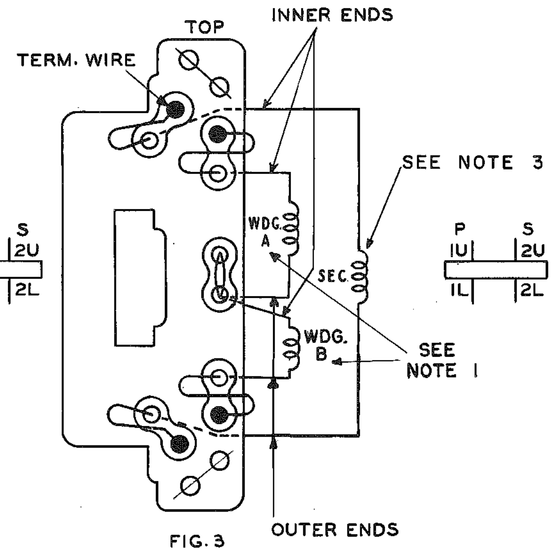

FIG. 3
DOUBLE WINDING
SINGLE ARMATURE
TYPE

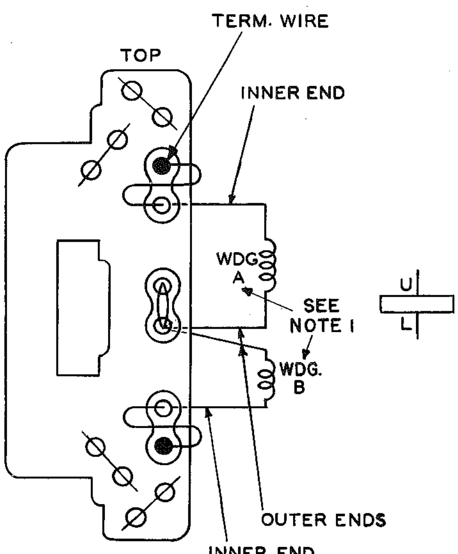

FIG. 4
SINGLE WINDING
SINGLE ARMATURE
TYPE

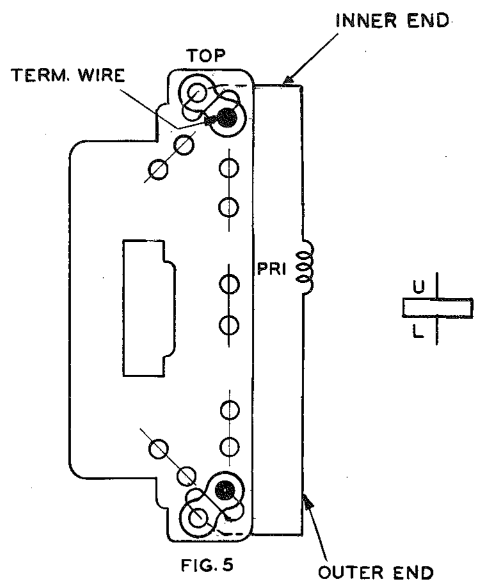

FIG. 5
SINGLE WINDING
SINGLE ARMATURE
TYPE

NOTES:

1. WINDINGS A AND B FORM PRIMARY.
2. WINDINGS A AND B FORM SECONDARY.
3. SECONDARY WINDING IS WOUND BETWEEN A AND B WINDINGS.
4. WINDING B IS NONINDUCTIVELY WOUND WITH RESISTANCE WIRE.
5. WINDING B IS INDUCTIVELY WOUND WITH RESISTANCE WIRE.

Fig. X-6 (Part 1) - AF, AG, AJ, AK, AL, and AM Relays - Winding Arrangements

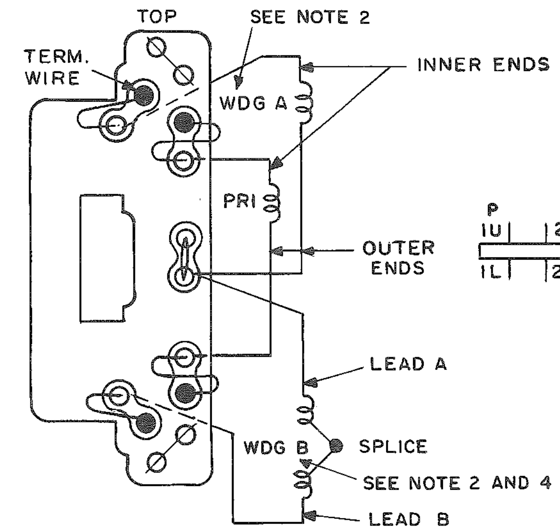

FIG. 6
DOUBLE WINDING
SECONDARY WITH NONINDUCTIVE SPLICE
SINGLE ARMATURE
TYPE

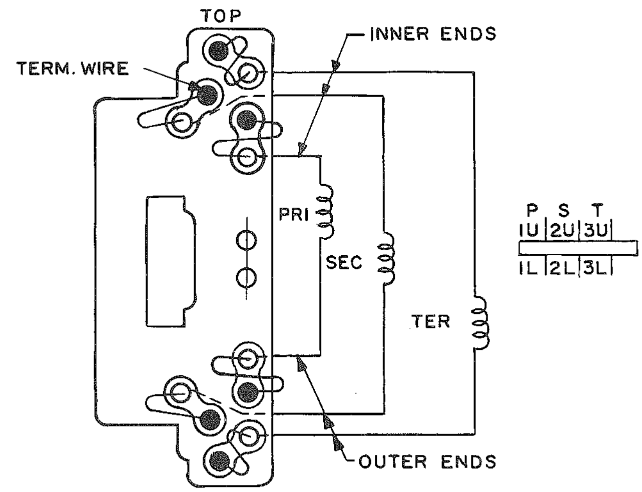

FIG. 7
TRIPLE WINDING
SINGLE ARMATURE
TYPE

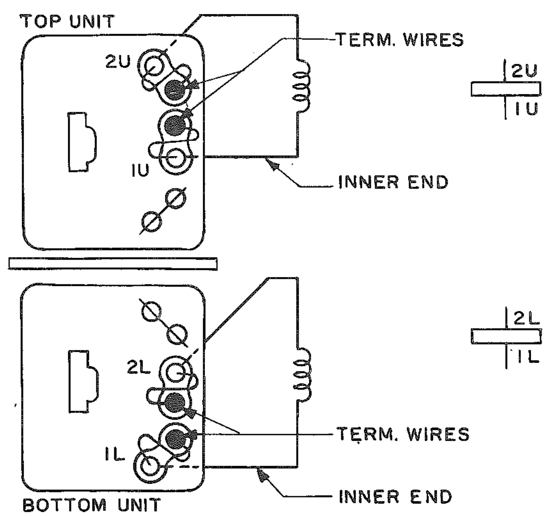

FIG. 8
SINGLE WINDING
DOUBLE ARMATURE
TYPE

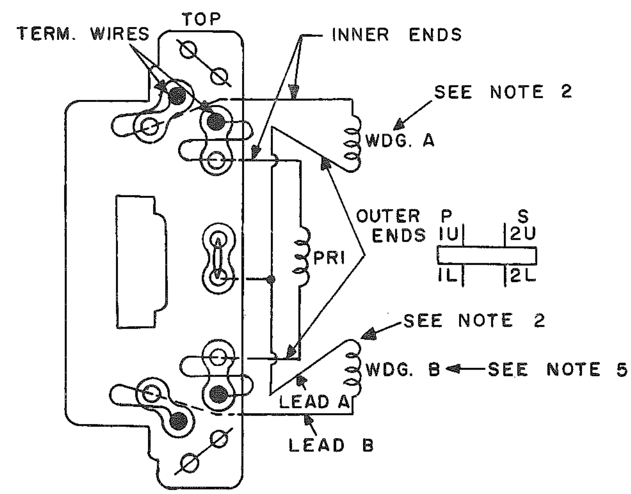

FIG. 9
DOUBLE WINDING
SECONDARY WITH INDUCTIVE WINDING
SINGLE ARMATURE
TYPE

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NOTES:
1. WINDINGS A AND B FORM PRIMARY.
2. WINDINGS A AND B FORM SECONDARY.
3. SECONDARY WINDING IS WOUND BETWEEN A AND B WINDINGS.
4. WINDING B IS NONINDUCTIVELY WOUND WITH RESISTANCE WIRE.
5. WINDING B IS INDUCTIVELY WOUND WITH RESISTANCE WIRE.

Fig. X-6 (Part 2) - AF, AG, AJ, AK, AL, and AM Relays - Winding Arrangements

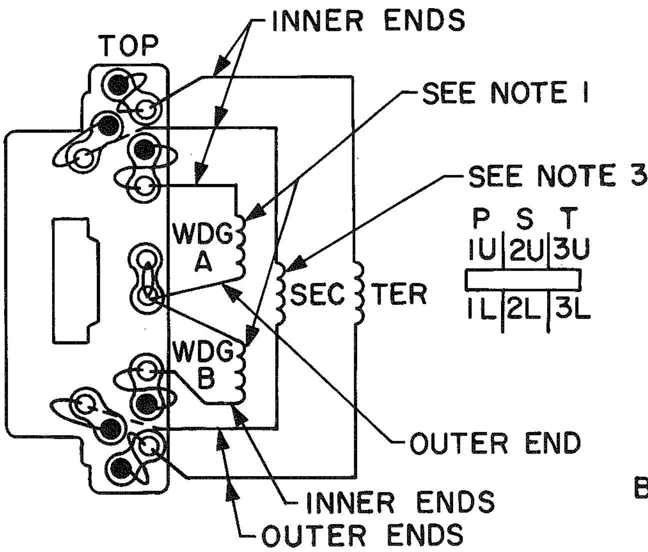

FIG. 10
TRIPLE WINDING-SINGLE ARMATURE TYPE

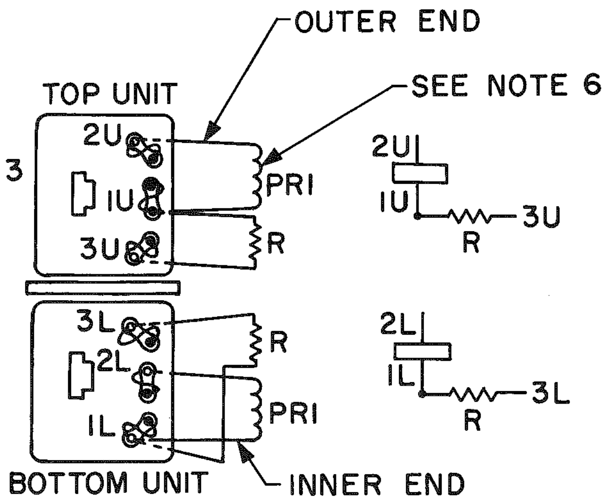

FIG. 11
SINGLE WINDING WITH SERIES RESISTANCE-DOUBLE ARMATURE TYPE

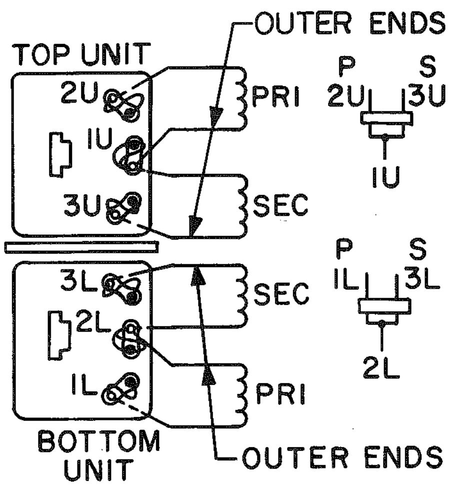

FIG. 12
DOUBLE WINDING-DOUBLE ARMATURE TYPE

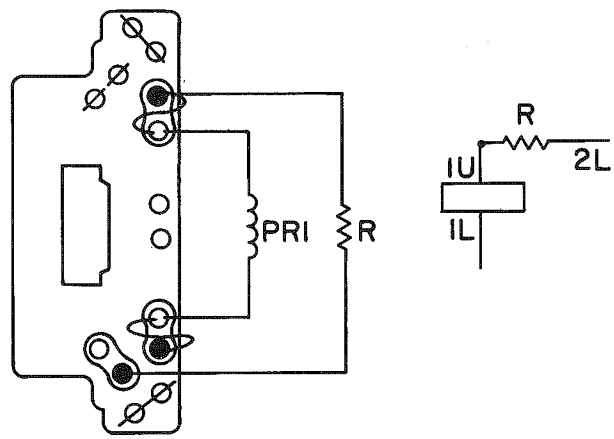

FIG. 13
SINGLE WINDING WITH SERIES RESISTANCE-SINGLE ARMATURE TYPE

NOTES:

1. WINDINGS A AND B FORM PRIMARY.
2. WINDINGS A AND B FORM SECONDARY.
3. SECONDARY WINDING IS WOUND BETWEEN A AND B WINDINGS.
4. WINDING B IS NON-INDUCTIVELY WOUND WITH RESISTANCE WIRE.
5. WINDING B IS INDUCTIVELY WOUND WITH RESISTANCE WIRE.
6. THE COIL OF THE TOP UNIT IS WOUND IN A COUNTERCLOCKWISE DIRECTION.

Fig. X-6 (Part 3) - AF, AG, AJ, AK, AL, and AM Relays - Winding Arrangements

X-75509

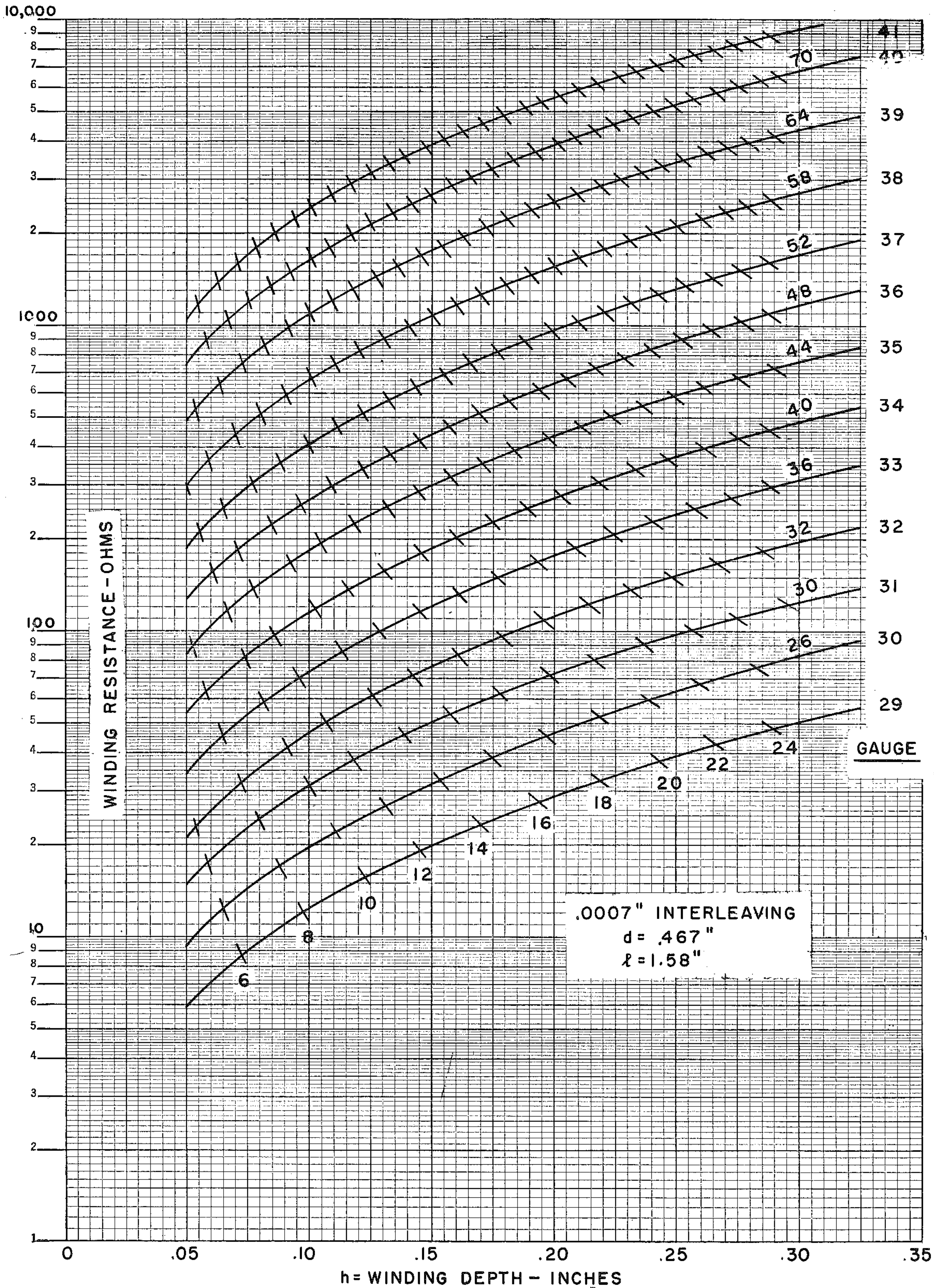

Fig. X-7 - Coil Resistance Versus Winding Depth AF Relays - Long Coil - 0.0007-Inch Interleaving

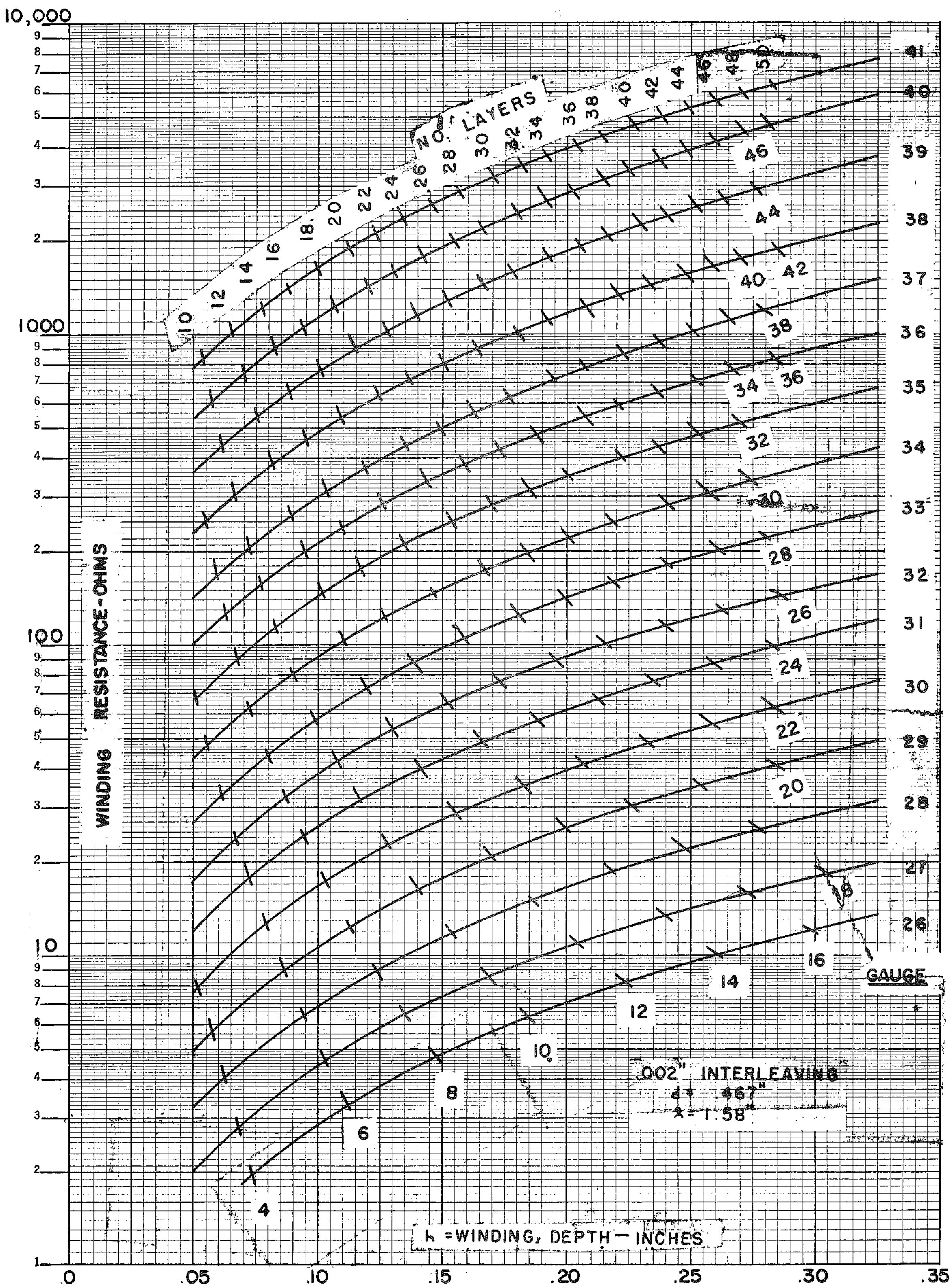

Fig. X-8 - Coil Resistance Versus Winding Depth AF Relays - Long Coil - 0.0002-Inch Interleaving

X-75509

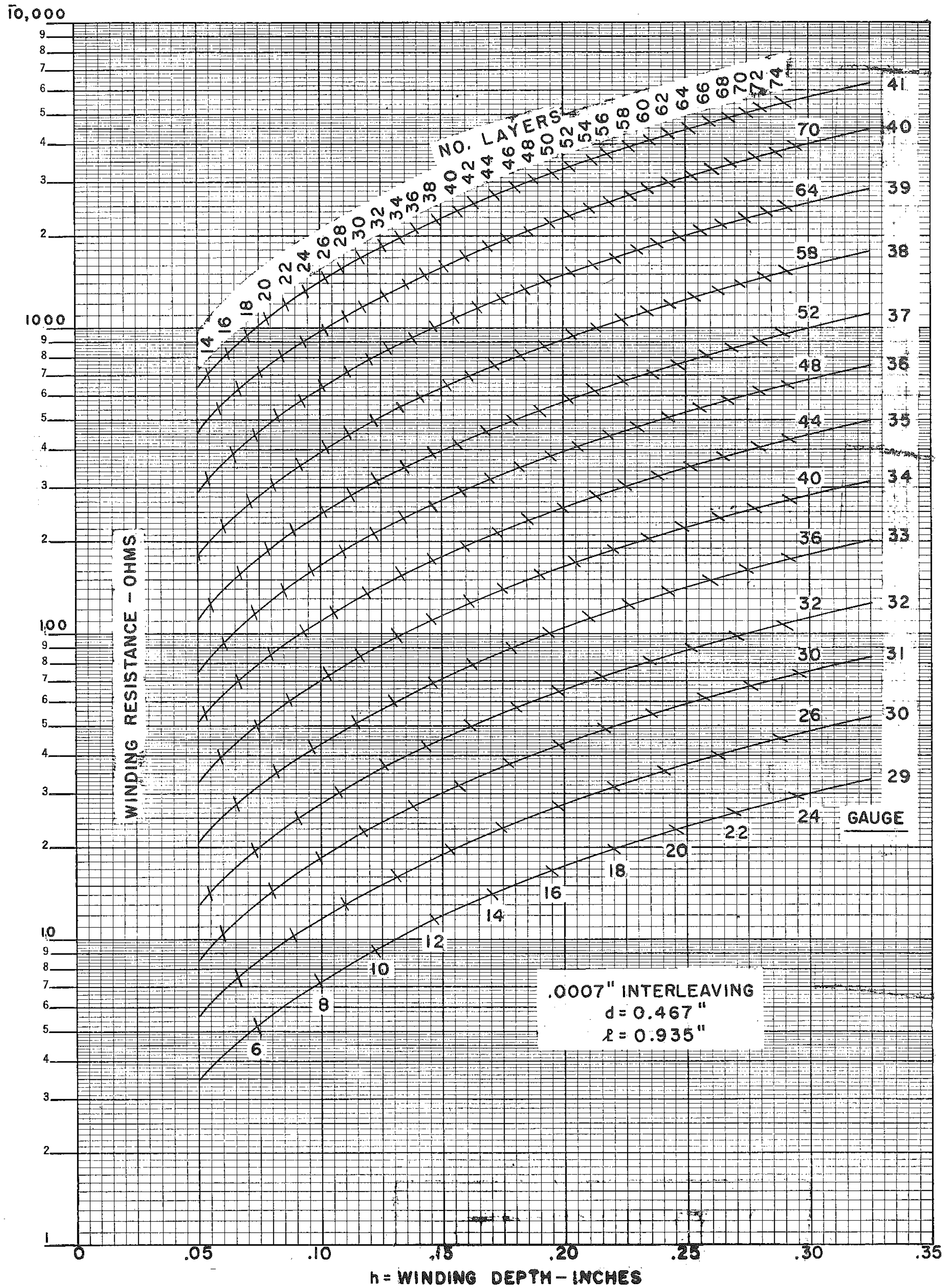

Fig. X-9 - Coil Resistance Versus Winding Depth AF Relays - Short Coil - 0.0007-Inch Interleaving

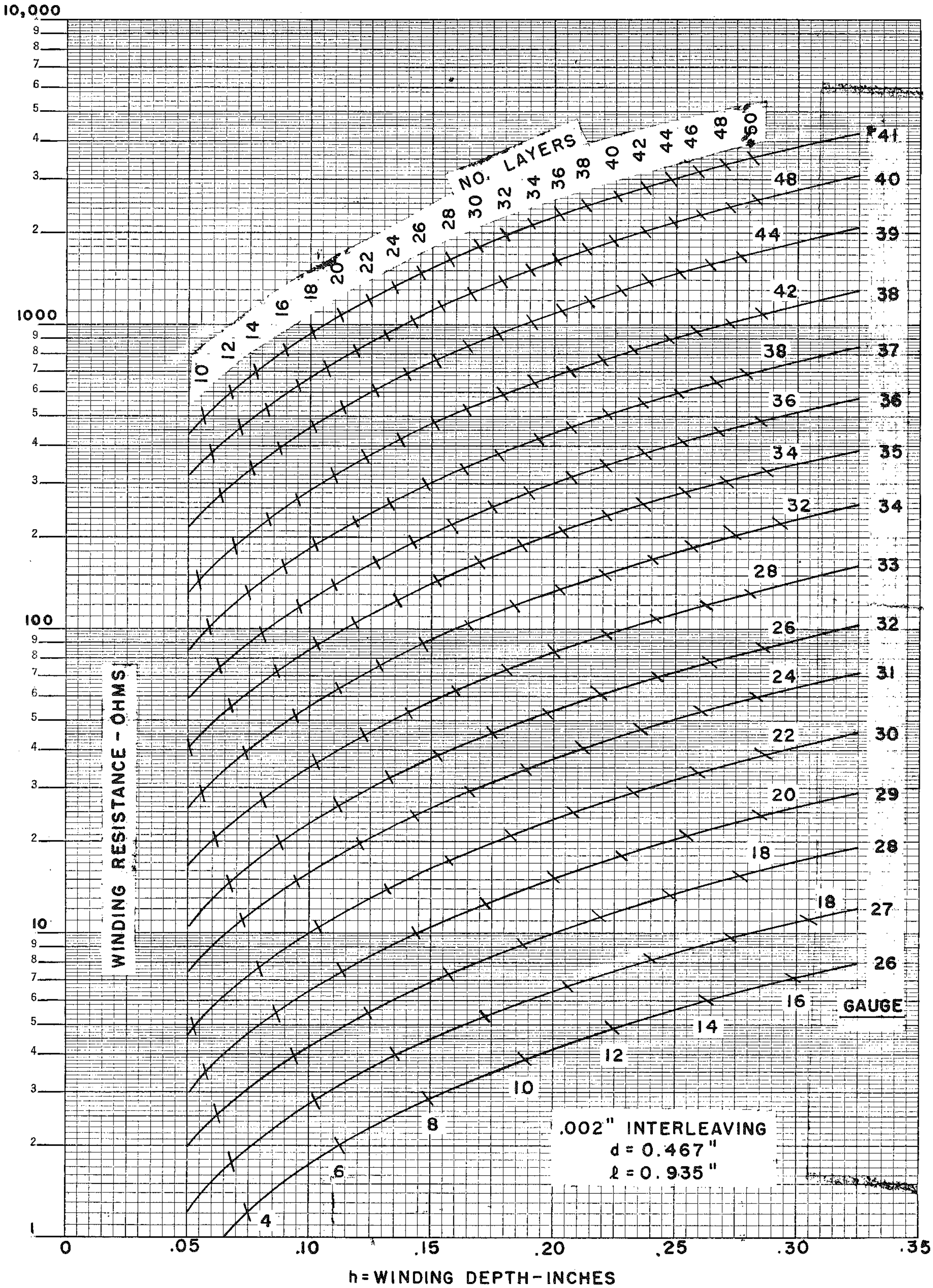

Fig. X-10 - Coil Resistance Versus Winding Depth AF Relays - Short Coil - 0.0002-Inch Interleaving

X-75509

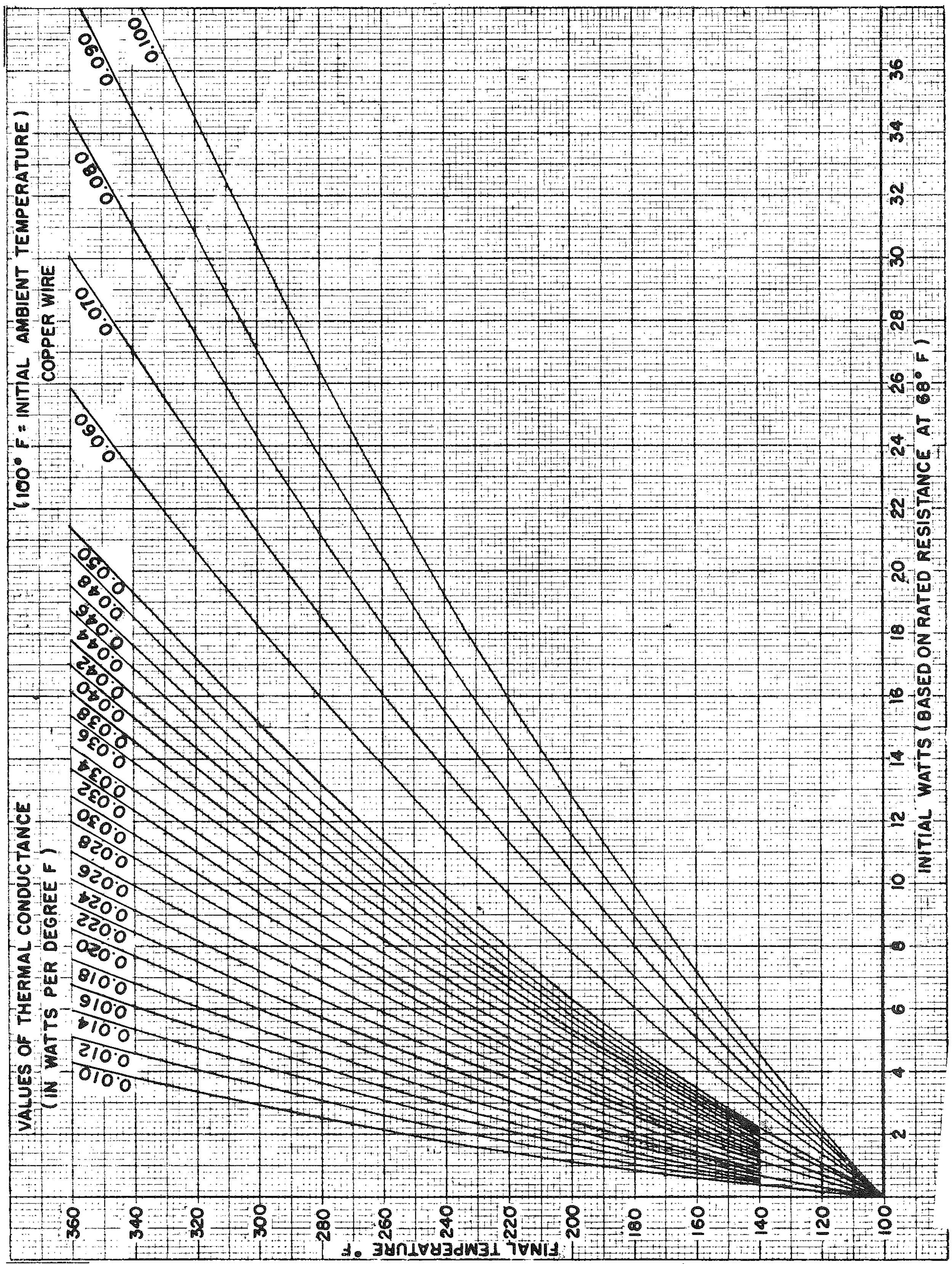

Fig. X-11 - Values of Thermal Conductance - In Watts per Degree F

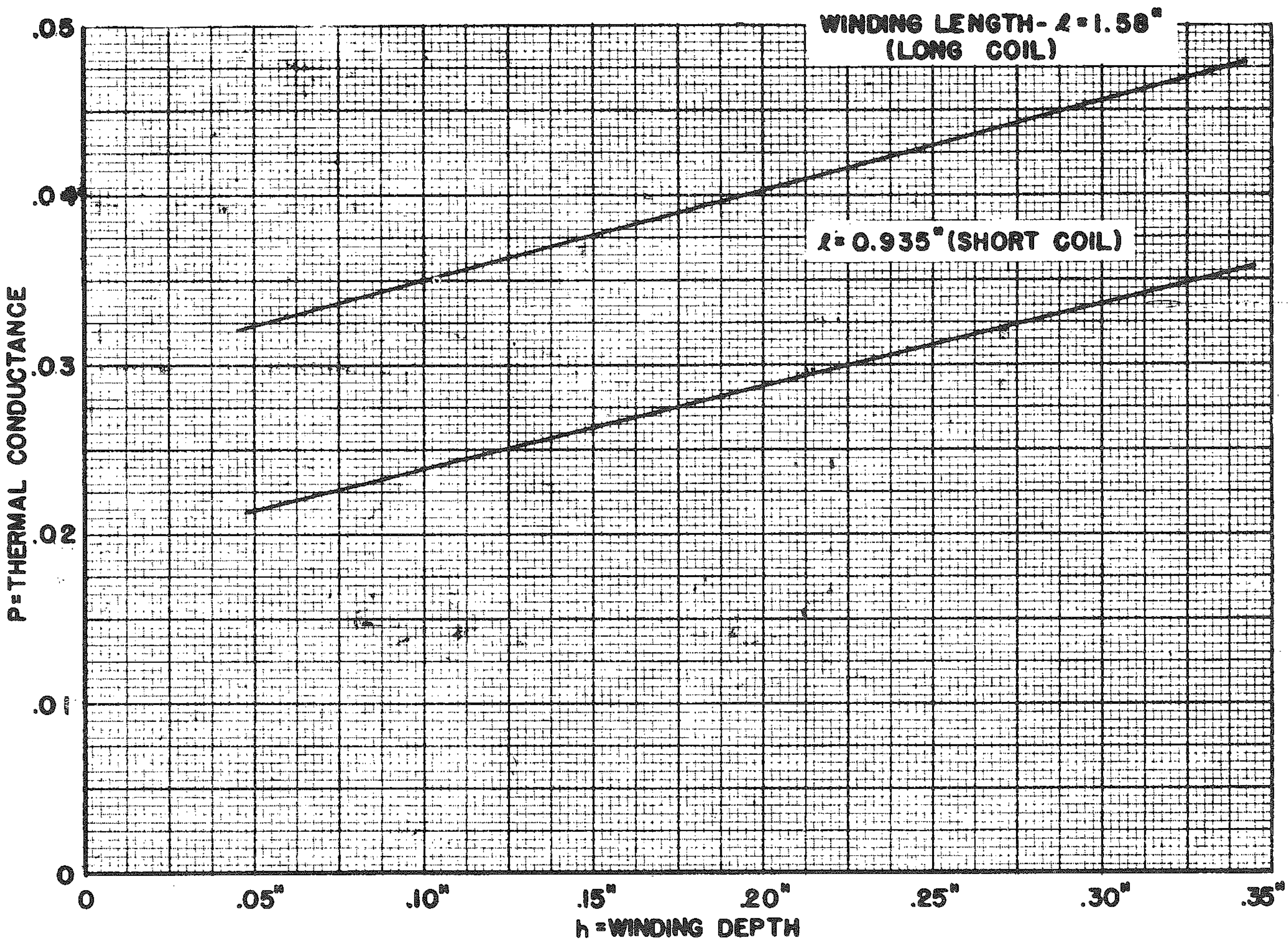

Fig. X-12 - Thermal Conductance (ρ) for Various Winding Depths - AF, AG, and AD Relays

X-75509

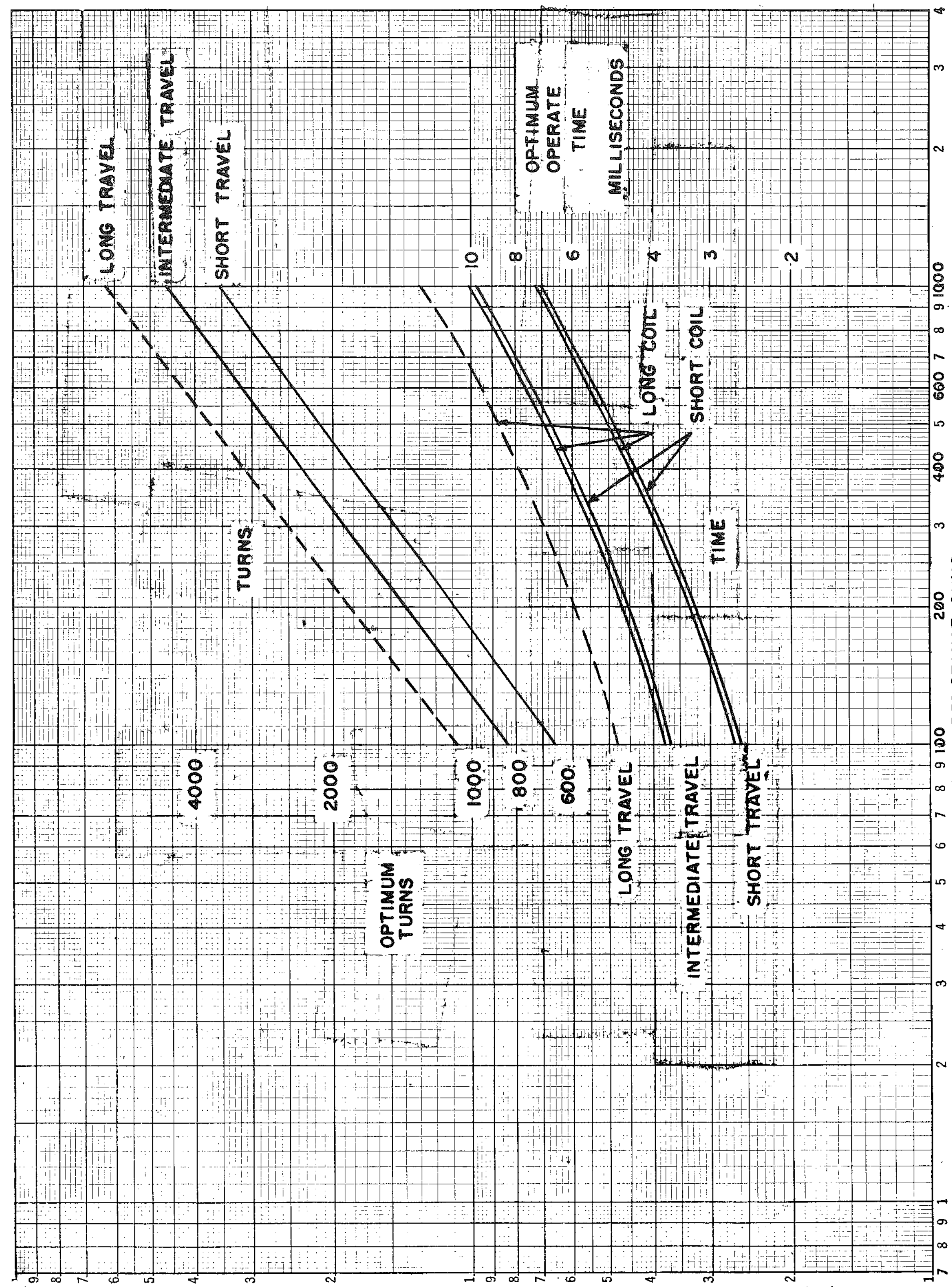

Fig. X-13 - AF Relay Speed Coils - Optimum Turns and Operate Time

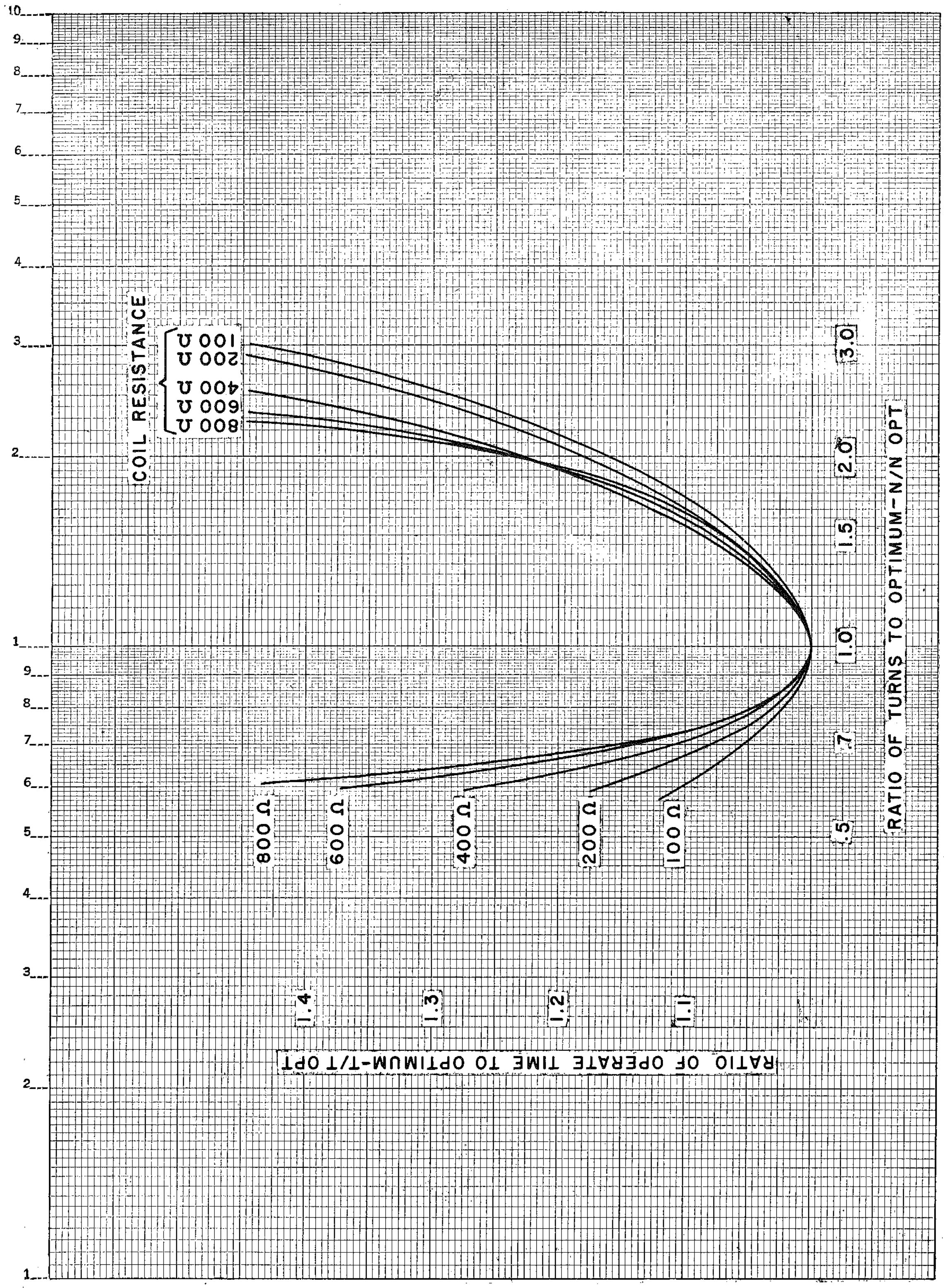

Fig. X-14 - Ratio of Optimum Turns and Operate Time