SECTION VII

OPERATE AND RELEASE TIMES

PART I - OPERATE TIMES

Listed Operate Times

Telephone relays are most commonly operated in local circuit on 48 volts. Since 48-volt applications are so common, the minimum, maximum, and average operate time values for each code on this voltage will be found in the code section (Section II). Some minor limitations on the use of these listed times are discussed later. It is expected that these listed times will greatly facilitate the computation of relay races for circuit analysis purposes.

For those cases where the operate times are not listed, or where the circuit conditions are not 48 volts, or where the circuit operation is not local circuit, it will be necessary to use the graphical solutions outlined in the following paragraphs.

Types of Problems

The most common problem that arises in relay application work in connection with relay operate time is determining the operate time of a given code of relay operating in local circuit. This problem is considered separately because it is so common and the solution is relatively simple.

A less common type of problem exists where the relay and circuit parameters are all, or in part, subject to the engineer's selection or design. This problem occurs, for example, when a new coil is designed, or where a 48-volt coil is used in a 130-volt circuit, assuming, of course, that an optimum design from a speed standpoint is needed. Under such conditions, it is possible to design for optimum speed in a straightforward manner. Furthermore, it is practicable, where compromises have been made with optima, to determine the penalty paid for the deviation from optimum design. The problem is considered separately, mainly because it is less often needed and its complexity justifies separate treatment.

Another type of problem arises where a relay is required to operate in series parallel arrangements of circuit elements involving inductances and capacitances. The solutions to the more general cases are usually so involved as to be impractical. However, in a great many cases, the problem can be simplified either by considerations of symmetry or by the use of simplifying assumptions. The method of handling some typical cases is covered in Appendix A.

A type of problem, of importance mainly to the relay engineer, involves the simulation of one relay circuit by another relay circuit that happens to be available. For example, assuming that an extreme capability relay is available, it is possible to use a single full winding on the structure and obtain complete data on relay operate times for all relay coils without rewinding the coil. In effect, the operate times are obtained in circuits that are mathematically similar, the difference being only in impedance level. Such translations are exact and yield very satisfactory data. The method is set down in Appendix B.

Definition of Minimum, Maximum, and Average Times

In most relay operate time problems the average, maximum, or minimum operate time may be required. The average time is, of course, obtained when all variables are average. It is not so obvious what the variables will be for minimum or maximum time. If the number of contributing variables is large, it may be uneconomical to consider all variables to be at their maximum adverse values. Furthermore, it may be physically impossible for two particular contributing factors to be simultaneously adverse because one variable is a function of the other; therefore, in stating the minimum or maximum operate times it is important that the conditions and assumptions be defined.

The maximum and minimum operate times listed in the code sections of this manual were obtained by means of the methods and data to be described later. In these data, allowances have been made for the probability that all variables will not be simultaneously extreme. Allowances have also been made where a variable is dependent upon some other variable, both of which cannot be simultaneously adverse. For example, the size of the airgap and the magnitude of the inductance are interrelated in such a way that when the airgap is increased, the inductance is decreased.

The minimum operate times listed in the code sections were obtained with minimum resistance and the maximum times with maximum resistance. The maximum resistance was taken to be the cold value on the assumption that no appreciable heating occurred during circuit operation. Actually, the maximum operate time for the relay when hot will be increased only about 5 percent for practically all local circuit relays.

The minimum operate times listed in the code sections were obtained at 50 volts and the maximum times at 45 volts. Since the voltages cannot be simultaneously adverse in a particular circuit relay race, a margin results to help balance the heating effect that tends to raise the maximum times as noted above. It is therefore concluded that a fair circuit analysis can be made of relay races by using the listed operate times and ignoring the effect of heating due to circuit operation.

Load-Controlled Versus Mass-Controlled Solutions

The complete solution for the operate time of a relay requires consideration not only of the time required to build the magnetic field up to the value needed to pull the load, but also the time required to move the armature system up to the relay contacts. The former time is commonly called electrical time, and the latter time is called mechanical or travel time.

A complete mathematical solution involving both mechanical and electrical considerations is too complex for practical use and in fact has never been obtained. It is usually found to be adequate to determine the operate time on the assumption that either the flux buildup, without armature motion, or the armature movement, is the more controlling factor in the operate time. Where the flux rise time is more controlling, the relay operate time is referred to as "load-controlled"; where the armature movement is more controlling, the operate time is referred to as "mass-controlled."

This should not be taken to mean that in the load-controlled solution the mass effect is neglected, or that in the mass-controlled solution the load effect is neglected. As will be seen, the mass-controlled solution includes the waiting time of the armature at the backstop, and the load-controlled solution includes a factor to allow for the travel time of the armature.

Choice of Mass-Controlled or Load-Controlled Method

In general, the load-controlled solution will be needed on the AF, AG, and AJ relays when the applied power is less than 2 watts and the mass-controlled solution when the power is above 2 watts. For cases in the vicinity of 2 watts, the mass-controlled solution should be tried first. If the time exceeds 0.010 second, average, the load-controlled solution should be used. The AK relay, due to the mass of the armature, is mass-controlled to about the 2-watt power level.

The following paragraphs explain the methods used for calculating the operate time.

Calculation of Load-Controlled Operate Time - AF, AG, and AJ Relays

The operate time is the time required to build up the magnetic field to the operate value plus an allowance for travel time:

$$t = (1+X)L(G_s+G_e+G_c)\log_e \frac{1}{1-q}$$

X = allowance for travel time

t = time in milliseconds

L = inductance for one turn in microhenries

G_s = sleeve conductance in kilomhos

G_e = eddy current conductance in kilomhos

G_c = coil conductance in kilomhos $= \frac{N^2}{R} \times 10^{-3}$

N = turns

R = resistance in ohms

$q = i/I$

i = just operate current in milliamperes

I = steady state current in milliamperes

Some of the above constants have various values depending on whether a minimum or maximum time is desired and whether the structure is an AF, AG, or AJ relay.

The maximum operate times for the AF relay are computed from Fig. VII-1. To compute the maximum operate times for the AG and AJ relays, Fig. VII-1 should also be used and the times as read should be increased by 20 percent for the AG relay and 10 percent for the AJ relay to correct for the higher inductance of these structures.

The minimum operate times for the AF, AG, and AJ relays are computed from Fig. VII-2 directly with no correction needed for the AG and AJ relays. This is because the minimum time curves are based on high airgaps where there is little difference in inductance for the three relay types.

The curves are based on unsaturated relays. When the operate adjustment extends into the saturation range, a correction is necessary when figuring the maximum operating time to allow for the decreased inductance. The correction for saturation effect is shown in Fig. VII-1. This correction is needed only on the more heavily loaded relays, as described later.

The computation for average time is covered later.

Construction of Curves

The graphs of Fig. VII-1 and VII-2 are constructed as follows: The left vertical scale is the resistance in ohms; the horizontal scale and the right vertical scale are time or time constant in milliseconds. The lines slanting downward from left to right represent the turns of the winding. The lines slanting upward from left to right represent the current ratio i/I or q, where i is the just operate current and I is the steady state circuit current. The curve designated NO SLEEVE represents the effect on the operating time of the eddy currents induced in the magnetic material. The curves designated 0.147-inch, 0.091-inch, and 0.46-inch cu for the copper sleeves and the 0.046-inch al for the aluminum sleeve represent the combined time constants of the eddy-current paths in the magnetic material and the various sleeves.

The insert graph of Fig. VII-1 shows the effect of saturation in reducing the electrical operate time. The maximum operate time as determined from Fig. VII-1 should be multiplied by the percentage read from the correction curve of Fig. VII-1 for the particular value of operate ampere turns in order to read the actual operating time.

Use of Fig. VII-1 To Obtain Maximum Operate Time

The maximum electrical operating time of a relay is determined as follows: Using the turns and the maximum resistance of the energizing winding, determine the point of intersection of the TURNS and RESISTANCE curves; projecting this point vertically downward, read the time constant of the energizing winding on the horizontal scale. If the relay has no sleeve, project the time constant of the energizing winding vertically upward to the NO SLEEVE curve and then horizontally to the right to read the sum of the time constant of the winding and the eddy-current time constant (2 msec) of the magnetic material. Project this total time constant horizontally until it intersects the line representing the ratio i/I and then vertically downward to read the maximum operating time of the relay. If the relay has a copper sleeve, the procedure is the same except that instead of projecting the time constant of the energizing winding vertically upward to the NO SLEEVE curve, it is projected upward to the proper sleeve curve and then horizontally to the right to read the sum of time constants of the energizing winding, the sleeve, and the magnetic material. The mechanical time is included in the q curves as drawn.

X-75509

In determining maximum electrical operating times, the operating current i should be the maximum or operate test requirement and the circuit current I should be the minimum or hot worst circuit current.

The rated turns and the maximum resistance should be used in determining the time constant of the energizing winding.

As an example, suppose it is required to find the maximum operate time of a 2500-ohm AF relay having 19,400 turns and operating in local circuit on 45-50 volts. The test operate current is 8.2 ma.

$$I = \frac{45}{2500 x 1.1} = 16.4 \text{ ma}$$

$$q = i/I = \frac{8.2}{16.4} = 0.5$$

$$NI = 19{,}400 x 8.2 = 160$$

In Fig. VII-1, find the point corresponding to 2750 ohms and 19,400 turns (63 msec on horizontal scale). Project vertically along 63-msec line to intersection with NO SLEEVE curve (65 msec on vertical scale). Project horizontally along 65-msec line to intersection with 0.5 CURRENT RATIO line. Project vertically and read 48 msec on horizontal scale. For 160 NI on the AF curve, read 0.96 for a saturation correction factor. The operate time is therefore 48x0.96 = 46 msec.

If the relay has appreciable heating during normal circuit operation, the relay resistance should be taken to be the maximum value when hot. It will be noted that if the current flow margin is good, the effect on the operate time will be insignificant.

Use of Fig. VII-2 To Obtain Minimum Operate Time

The procedure for determining minimum electrical operating times from Fig. VII-2 is the same as the procedure for maximum operating times except as described below.

In determining the minimum electrical operating times, the operating current should be the minimum or equal to the nonoperate test current flow requirement and the circuit current I should be the maximum based on maximum voltage and minimum resistance. If no nonoperate requirement is specified, then the equivalent nonoperate ampere-turn value should be read from the nonoperate capability curves for minimum tension and minimum armature gap (see Section IX for capability data). For AF and

AJ relays with 6-mil stop discs and for the AG relay, these ampere turn values are:

Arm. Travel	AG (20 gm)	AF, AJ (30 gm)
short	32 NI	48 NI
intermediate	53 NI	69 NI
long	71 NI	88 NI

The rated turns and the minimum resistance should be used in determining the time constant of the energizing winding.

Use Of Fig. VII-2 To Obtain Average Operate Time

The average operate time is obtained with all constants taken at the average, or nominal, value. The average operate current flow of the relay should be taken as the average of the operate and nonoperate readjust values. Where no nonoperate value is specified, the average operate value can be obtained by averaging the ampere turns obtained from the operate and nonoperate ampere turn capability curves (Section IV) for a load of 70 grams and nominal airgap. For AF and AJ relays with 6-mil stop discs and for the AG relay, these values are:

Arm. Travel	AG	AF, AJ
short	76 NI	93 NI
intermediate	112 NI	127 NI
long	135 NI	156 NI

The minimum operate time curve, Fig. VII-2, should be used. The operate time as read should be increased by 5 percent for the AF, 10 percent for the AJ, or 20 percent for the AG to allow for the greater inductance of the average structure in each case.

Calculation of Mass-Controlled Operate Time Using Fig. VII-3 or VII-4 - AF, AG, and AJ Relays

The operate time is the waiting time of the armature plus the time to move the armature from the backstop to the contacts. The method applies only where the rate of flux rise is so great that the contact load is insignificant in delaying the armature motion. This assumption is justified when the average operate time is less than 10 msec.

The operate time is obtained from Fig. VII-3 and VII-4, which have been obtained from test data. The data are given for the average conditions and provide the average operate time to close the average contact. The average time to the first or the last contact is found by subtracting from, or adding to, the average operate time, the following travel allowances.

Coil Resistance

Arm. Travel	16 ISW 90	270	395 or 400	700
	ohms			
Short	0.1	0.1	0.2	0.3
Intermediate	0.4	0.5	0.7	1.0

The data in Fig. VII-3 and VII-4 apply only to relays with maximum 60-gram armature back tension. This includes all the 4.4-, 16-, 270-, 395-, 400-, and 700-ohm coils except those with nonoperate or release requirements. Relays with nonoperate or release requirements have a maximum 85-gram armature back tension. This increases the operate time about 10 percent.

Relays using the short coil have an operate time faster than the values in Fig. VII-3 and VII-4. To obtain the short coil operate time, take 95 percent of the values from Fig. VII-3 or VII-4.

Average Operate Time

Determine the watts expended in the relay and series resistance, if any, using average voltage and average resistance. Also calculate the conductance, N^2/R, using specified turns and average resistance including any series resistance. Using the graph of Fig. VII-3 for short travel or Fig. VII-4 for intermediate travel, read the average operate time in msec, interpolating between the power curves as necessary.

As an example, suppose it is required to find the average operate time of a 400-ohm AF relay having 3330 turns short armature travel and operating in local circuit on 48 volts:

$$\text{Avg power} = \frac{(48.5)^2}{400} = 5.9 \text{ watts}$$

$$\text{Conductance} = \frac{(3330)^2}{400} = 27.2\text{x}10^3 \text{ mhos} = 27.2 \text{ Kmhos}$$

In Fig. VII-3, for short armature travel, the average operate time is found to be 5.3 msec.

Minimum and Maximum Times

The minimum and maximum times are determined by finding the average time to the first or last contact and allowing ±30 percent variation.

For applications, such as the AMA Center, where the maximum operate times are specified for troubleshooting reasons, and where it is feasible to turn the relays to meet the specified operate time requirement, limits of ±20 percent from the average may be specified.

Calculation of Operate Time - AK Relays

Both the short and the intermediate travel AK relays operating with an applied power of 2 watts or more are essentially mass-controlled and the contact load has practically no effect on the operate time. The minimum and the maximum operate time for short and intermediate armature travel is shown for the mass-controlled condition on Fig. VII-4A and VII-4B.

Since these figures are plotted for the minimum and the maximum operate times, the resistance and voltage used in computing the power and coil constant $\frac{N^2}{R}$ should be the limiting values, ie, minimum voltage and maximum resistance for the maximum operate and the reverse values for the minimum operate time. The average operate time is the mean of the maximum and the minimum time.

The operate time curves include a factor for contact stagger and, therefore, the minimum time curves are the time to the first contact to function and the maximum times are to the last contact.

The maximum operate time for relays operating on less than 2 watts, based on average resistance and voltage, should be computed by means of the following expression for load-controlled operate time:

$$t = L(G_c + G_s + G_e)\log_e \frac{1}{1 - \frac{i}{I_o}}$$

X-75509

where t = relay operate time in seconds

L = inductance per turn as shown in Fig. VII-6A

G_c = coil conductance $\frac{N^2}{R}$ in mhos

G_s = sleeve conductance (if sleeve is used)

G_e = core conductance = 10,000 mhos

i = test operate or test nonoperate current

I_o = circuit current

The value of L should be taken for a travel value of one half the armature travel of the relay in question (0.015-inch for short travel and 0.022-inch for intermediate travel). The values of the expression $\log_e \frac{1}{1 - \frac{i}{I_o}}$ may be obtained from Fig. VII-4C, which shows this expression plotted for values of the current ratio $\frac{i}{I_o}$

The above expression gives the electrical buildup time for the coil. To obtain the maximum operate time, a mechanical time of 1.3 msec for short armature travel and 2.7 msec for intermediate travel should be added to the electrical time computed. The minimum operate time for all relays should be computed from the mass-controlled condition Fig. VII-4A or VII-4B.

Calculation of Maximum Contact Stagger Time

AF, AG, and AJ Relays

Where the operate time is mass-controlled, the stagger time will not exceed 1 msec for short travel or 2 msec for intermediate travel.

Where the operate time is load-controlled, compute the maximum operate time using the load-controlled method, as explained previously. In Fig. VII-5, using 80 percent of the computed maximum operate time, read the maximum stagger time. The data for the AF relay is for a particular q value (ratio of test operate to worst circuit operate) and must be corrected for other q values as shown in Fig. VII-5. This curve is a composite curve; it does not imply that the maximum stagger is obtained on the stiffest relay.

AK Relays

The stagger times for the AK relay are given in the following table.

Power watts	Short Travel (msec)	Intermediate Travel (msec)
1	1.3	2.7
2	1.0	2.0
3	0.9	1.8
5	0.8	1.6

Design for Highest Speed

The preferred coils, designed for speed use, provide highest speed for 48-volt operation. For highest speed design at other voltages and for series circuits, the following rules should be followed:

1. Use maximum power. The allowable power is usually limited by considerations of heating, power drain, contact current, and tube life.
2. Use minimum armature travel. It is advisable to examine the circuit to determine if sequences are necessary. The penalty for increased armature travel is evident in Fig. VII-3 and VII-4.

3. Use restricted armature tension. All relays using the 4.4-, 16-, 270-, 395-, 400-, and the 700-ohm coils have 45 ±15 gram armature tension specified in the M specification. The operate time will be increased about 20 percent if the armature tension is raised from 45 to 90 grams. The operate time will be increased about 60 percent if the armature tension is raised from 45 to 180 grams.

4. Use optimum turns. If the relay has too few turns, it will be slow because of poor margins. If it has too many turns, it will be slow because of a large winding time constant. For each case there will be an optimum value of turns depending on the power input and the armature travel. Any deviation from optimum should always be on the high side to insure positive operation of the relay.

   For mass-controlled cases, the optimum turns will be evident from Fig. VII-3, VII-4, or X-13.

   For load-controlled cases, without copper sleeves, the optimum turns are approximately twice the turns needed to just operate the relay load.

   For copper sleeve relays, the optimum turns are greater than twice the turns needed to just operate the relay. Winding space limitations usually preclude the achievement of the optimum value.

Inductance Curves

Inductance values, as a function of the airgap, are shown in Fig. VII-6 for the AF, AG, and AJ relays and Fig. VII-6A for the AK relay. Appropriate values of inductance taken from these curves have been used in the methods set down in the preceding paragraphs. It should be understood that these curves show the buildup inductance of the relay obtained from the slope of the magnetization curve with, as the name implies, increasing flux.

The curves will supply the inductance constant for use in computing the operate time under some conditions. For example, if the operate time of a series relay or switch of another type is needed, and the AF, AG, or AJ relay is a series or shunt element in the operating circuit, the inductance constant for the AF, AG, or AJ relay may be needed to make the computation.

The inductance constant shown in Fig. VII-6 and VII-6A is for one turn. For a structure of N turns the inductance will be obtained by multiplying the inductance constant by N^2.

APPENDIX A

EQUIVALENT SIMPLE CIRCUITS FOR SERIES OR PARALLEL RELAY CIRCUITS

General

The engineering data provided earlier in this section applies to a relay operating in local circuit or in series with a resistance and releasing with a contact protection network. In practice, relays often operate in series or parallel with one or more other relays and resistances. The contact protection network may be across the operating contact, the entire series circuit, or the parallel circuit.

These more complex circuit configurations do not seriously complicate the estimation of the operate and release time for the relay. For a great many of the cases, it is possible to reduce the circuit to a simple equivalent for which the data presented earlier in this section will apply.

For the purpose of computing operate and release times, the equivalent circuit may be defined as one in which the ampere-turn transient, during operate or release, is not altered. This unchanged ampere-turn transient in the equivalent circuit is guaranteed provided the factors L/R, r^C, LC, and NI remain unchanged (where L is the inductance of the operate path, R is the resistance of the operate path, C is the protection capacitance, r is the resistance in series with the protection capacitance, N is the turns on the relay, and I is the steady-state current when operated). In practice, the factor rC is found to have very little effect on the computed times, so that for practical equivalence only the factors L/R, LC, and NI must be equivalent in order to guarantee equivalent operate and release times.

Applications of Equivalent Circuit Theory

Figure VII-7A shows a relay circuit of the type commonly used in the AMA circuits. Because the relays are in series and because the contact protection is not per relay, the data and curves cannot be directly applied. It is desired to reduce this circuit to a simple equivalent involving only one relay and an equivalent contact protection. This case is simple and the equivalent can be drawn almost directly and then the factors L/R, r^C, LC, and NI checked to show equivalence.

In Fig. VII-7B, the contact protection has been connected to battery instead of ground, which does not alter the transient at all. Also the 90-ohm external resistance is distributed equally between the two series relays. In Fig. VII-7C, the protection network has been distributed equally between the two relays. The dotted line connects points of equal potential and may therefore be added or discarded without affecting the transient. Fig. VII-7D assumes the dotted connector in place and the battery divided equally between two equal circuit sections. The equivalent in this case has been derived in a simple manner because of the symmetry of the parts of the circuit. Fig. VII-7A and VII-7D are shown to be equivalent by noting that the factors L/R, NI, r^C, and LC are unchanged.

Although the circuit of Fig. VII-7 is typical, the theory is not limited to such simple cases. In Fig. VII-8A a circuit is assumed in which the series relays have different windings. Here the total series resistance of the operate path must be distributed in proportion to the factor N^2 so as to make the time constant L/R (proportional to N^2/R) equal in each relay. This has been done in Fig. VII-8B and the protection connected to battery as before. In Fig. VII-8C, the protection capacitance has been divided into series components inversely proportional to N^2 so as to make the factor LC (proportional to N^2C) equal in each relay section. Also, in Fig. VII-8C the resistance in series with the protection capacitance has been distributed in proportion to the factor N^2 so as to keep the factor rC equal in each relay section. The dotted line connects points of equal potential throughout the transient and therefore may be added or removed, as required, without changing the current distribution. Finally the voltage has been divided into series components (proportional to N^2) in order to keep the factor NI unchanged in each relay and the circuit has been split, as shown in Fig. VII-8D. The factor L/R, NI, rC, and LC are calculated in Fig. VII-8A and VII-8D for a recheck of the equivalence between the original and final equivalent relay circuits.

In Fig. VII-9A, a parallel circuit is considered. The steps to arrive at the equivalent in Fig. VII-9C are almost obvious. The method can be extended to any number of relays in parallel, not necessarily of the same resistance, as long as the time constant for each relay is the same, which is practically true for all full wound relays on a given structure.

APPENDIX B

SIMULATED RELAY CIRCUITS

In compiling data for operate and release times of relays, particularly of new designs, it is often necessary to test a number of samples having various windings. Furthermore, if an extreme capability relay structure is available, it may be desirable to rewind the relay or remove turns to simulate the winding desired. This complication can be avoided by using a single winding on the extreme capability relay and changing all other circuit constants in such a way that the ampere-turn transient in the relay during operate and release is unaltered thereby resulting in unchanged operate and release times.

The rule for such equivalent circuits is as follows:

It is desired to test a relay circuit for operate and release times. The desired circuit is made up of a total series resistance in the operate path of R ohms, a relay with N turns, and a battery of E volts. The contact protection consists of a capacitance of C mf and a resistance of r ohms. The available structure has N' turns. The required circuit can be simulated insofar as operate and release times are concerned by using the following equivalents.

turns = N'

resistance = $\left(\frac{N'}{N}\right)^2 R$

voltage = $\left(\frac{N'}{N}\right) E$

protection capacitance = $\left(\frac{N}{N'}\right)^2 C$

protection resistance = $\left(\frac{N'}{N}\right)^2 r$

A check for equivalence between the desired and the simulating circuit can be obtained by noting that the factors L/R, NI, LC, and rC are unchanged. Typical examples are given in Fig. VII-10.

A limitation of the simulating circuit is that no visible spark should occur on the actuating contact during release since the voltage of the simulating circuit may exceed the sparking potential of air. It is therefore recommended that the test structure be wound with 3000 turns since this value will allow equivalents as low as 750 turns without exceeding 200 volts in the test battery. It is also recommended that the actuating contact be a fast opening contact to further reduce the possibility of sparkover and that the protection capacitor be capable of the resulting peak voltages.

PART II - RELEASE TIMES

General

The minimum, maximum, and average releasing times for the various coded relays, on 45 to 50 volts, local circuit, and without contact protection, are listed in the code section (Section II). For those cases where contact protection is used, it will be necessary to compute the release times as outlined later in this section. This section covers AF, AJ, and AK relays only, as the AG slow-release relays require special treatment and are covered in Section IX.

Definition of Minimum, Maximum, and Average Times

Release time is that interval from the time the relay winding circuit is opened to the instant that a contact is actuated. This would be the first contact to be actuated in the case of minimum release time, the average contact for average release time, and the last contact for maximum release time.

The data shown are for relays without contact protection unless the data specifically states that contact protection is used.

The release time consists of three parts:

X-75509

Electrical Time. The time necessary for the flux to decrease to a point that will allow the release of the armature from the core.

Travel Time. The time necessary for the armature to move sufficiently to actuate the nearest contact.

Stagger Time. The time necessary for the armature to move from the nearest to the farthest contact. For AF, AJ, and AK relays the maximum stagger is 1 msec for short travel and 1.5 msec for intermediate travel for relays releasing an open circuit. Relays releasing under shunt conditions, or relays with copper sleeves, may have an appreciable stagger time and will require special consideration.

Factors Controlling Release Time

The release time (t) of a relay is given by the equation $t = G\left[\frac{\varphi''-\varphi_o}{NI}\left(\frac{\log z}{z-1} - \frac{1}{z}\right)\right]$ where

t = electrical time

G = conductance

NI = release ampere turns

$$z = \frac{\varphi''-\varphi_o}{\varphi-\varphi_o}$$

φ'' = soak flux

φ_o = residual flux

φ = flux corresponding to the release ampere turns

The term $\frac{\log z}{z-1} - \frac{1}{z}$ is substantially a constant in the normal range of release ampere turns for the AF, AJ, and AK relays. The release time for any given load will, therefore, be proportional to G.

The conductance term G is made up of three parts: the coil conductance (G_c), the sleeve conductance (G_s), and the eddy-current conductance of the core of the relay (G_e). The eddy-current conductance is always present, but the coil conductance is present only when the relay releases from a short circuit or with a resistance in parallel with the winding, and the sleeve conductance is present only when a sleeve is provided on the relay.

The coil conductance may be determined from the relay winding data. $G_c = \frac{N^2}{R} \times 10^{-3}$ kilomhos where N is the turns on the coil and R is the total circuit resistance including any resistance in series or in parallel with the relay coil. If the relay is releasing on open circuit with no contact protection or shunt resistance, there is no closed circuit for the coil and G_c is zero.

The sleeve conductance is also in the form of $\frac{N^2}{R}$, but $N^2 = 1$ since the sleeve is considered a single short-circuited turn. The problem therefore reduces to the determination of the resistance of the sleeve. The values of sleeve conductance for the sleeves used on the wire spring relays are:

Sleeve	Max G_s	Min G_s
AF,AG, and AJ Relays		
0.046 in. aluminum	44.0 kmhos	38.3 kmhos
0.046 in. copper	73.6 kmhos	65.6 kmhos
0.091 in. copper	135.5 kmhos	125.0 kmhos
0.147 in. copper	200.5 kmhos	189.0 kmhos
AK Relays		
0.069 in. copper	112.0 kmhos	100.0 kmhos

The core conductance has been measured and found to be 5 kilomhos for the AF, AG, and AJ relays and 10 kilomhos for the AK relay. It is simpler and more accurate to use a measured value than to estimate a value from the relay constants.

The release time curves are based on the just hold, or the just release, ampere turns of the relay. These release ampere turns are determined as outlined in the following paragraphs.

Release Ampere Turns (NI) for Maximum Release Time

The data for maximum release time are based on the test release ampere turns of the relay. The release ampere turns are obtained by determining the readjust release value as shown below and multiplying by 95 percent to obtain the test value. A release requirement offers the best method of controlling the maximum release time in order to obtain the lowest maximum release time for a particular relay.

Relays With Operate Requirement Only

The release ampere turns are found by reading the operated load grams of Table IX-6 on the release curve for 300-ampere turn soak and the proper stop-disc height in Fig. IX-13, IX-19, IX-25, or IX-35 depending on whether an AF, AJ, AJ relay with laminations, or AK relay is being considered. If the relay has a specified minimum armature back tension of less than 30 grams, the operated load should be reduced by an amount equal to the difference between the specified back tension and 30 grams.

Relays With Nonoperate Requirement

The operated gram loads in Table IX-6 are based on a 30-gram armature back tension. Relays with a nonoperate requirement may have a back tension in excess of 30 grams as read on the nonoperate curve, which is based on a good magnet. If the nonoperate ampere turns were read on the operate pull curve, which is based on a poor magnet, a back tension in the order of 30 grams would result. Thus the nonoperate may not increase the back tension above 30 grams in the limiting case of a poor magnet and maximum unoperated airgap. Relays with a nonoperate should, therefore, be treated the same as relays with only an operate requirement.

Relays With Release Requirement

Multiply the release current flow value specified by the number of turns to obtain the readjust ampere turns.

Release Ampere Turns for Minimum Release Time

The release ampere turns for the minimum release time are based on the test hold ampere turns. These are found by determining the readjust hold value as shown below and multiplying by 105 percent to obtain the test value. The hold is used since the relay may release on a value just below the hold value.

Relays With Operate Requirement Only

The load used is the maximum operated gram load in Table IX-2. These loads are based on a 60-gram armature back tension. The speed coils (4.4-, 16-, 270-, 395-, 400-, or 700-ohm) have a maximum 60-gram back tension specified in the manufacturing requirements, but the other coils have no limit on the back tension as long as they meet the operate requirement. With the exception of the relays using the speed coils listed above, the operated gram loads of Table IX-2 should be increased by 30 grams to allow for the actual back tension that is likely to be encountered on the relays. The ampere turns on which the relay will just release are found by reading the maximum operated gram load on the hold pull curve for 300-ampere turn soak and the proper stop-disc height of Fig. IX-12, IX-18, IX-24, or IX-34 depending on the type of relay being considered.

Relays With Hold Requirement

Multiply the hold current flow value specified by the number of turns to obtain the readjust ampere turns.

Relays With Nonoperate Requirement

Relays with a nonoperate requirement are figured in the same way as those with only an operate requirement.

Release Time on Open Circuit With No Shunt

The release times of the ordinary AF, AJ, or AK relay are in the range of 1 to 15 msec. When adjusted on the same release ampere turns, the AF and AJ relays have essentially the same release time where no contact protection is used. The constants controlling the rate of flux decay are small unless a time delay sleeve or shunt is provided. This may increase the minimum time to about 50 msec. Minimum release times greater than this require the use of the AG relay which has special design features to provide longer release times. Faster release times can be obtained by using 0.014-inch or 0.022-inch stop discs on the AF or AJ relays and heavy spring loads.

Fig. VII-11 and VII-11A show the maximum and the minimum release times for relays releasing on open circuit with no shunt, sleeve, or protection. These are the times to the first contact for relays with 0.006-inch stop discs. If the stop disc is other than 0.006-inch, the release times should be corrected by the factors shown in Fig. VII-12. This may be an important correction and should not be overlooked. The stagger time should be added to the maximum time obtained from the release time curves.

The release times shown in Fig. VII-11 and VII-11A are based on a 300-ampere turn soak. Although the times may vary as much as 10 percent for the extremes of high soak and high release ampere turns, it does not appear necessary to complicate the figuring of release times by introducing a correction for high soak values. The maximum effect of the soak on the releasing time is obtained at high release ampere turns, which indicates a stiff relay and therefore fast release times, and the use of a coil developing about 500-ampere turns. Very few coils will develop 500-ampere turns and the 10-percent effect on the release times at the high release ampere turns is only a fraction of a millisecond. It is concluded therefore that the effect of soak values of 250 or more ampere turns can be neglected. For soak values of 200-ampere turns, reduce the release times by 3 percent, and for soaks of 150-ampere turns or less by 5 percent.

Average Releasing Time

The average release time is obtained by taking 80 percent of the maximum operated gram load from Table IX-2 and reading the release ampere turns for this load on both the hold and release pull curves. Read the release time for the hold ampere turns on the minimum release time curve and the release time for the release ampere turns on the maximum release time curve. The average of these two readings is the average release time.

X-75509

Release Time With Resistance Shunt

Under this condition G_c will be something greater than zero and will be found from $G_c = \frac{N^2}{R_1+R_2}$ where

N = number of turns in coil

R_1 = resistance of coil

R_2 = resistance of shunt

Fig. VII-13 shows the maximum release time of the AF and AJ relays plotted against the conductance in kilomhos for different ampere-turn release values and 0.006-inch stop discs. Fig. VII-14 shows the minimum release time for the same conditions. Fig. VII-13A and VII-14A show the corresponding values for the AK relay. The release times are found by reading the previously determined release ampere turns for the value G_c determined from the coil constants. Although the curves are plotted for the coil and/or sleeve conductance only, the effect of the eddy-current conductance of the core (G_e) is also included in the release time curves. For open circuit release with no sleeve or shunt, $G_c + G_s$ is zero. The release time for AF or AJ relays with other than 0.006-inch stop discs is found by obtaining the time for the 0.006-inch stop discs and applying the correction factors from Fig. VII-12. The stagger time may be long and will require special consideration if it affects the circuit operation.

Release Time With Sleeves

In the release time of relays with sleeves, particularly those with large sleeves, the major portion of the release time is due to the slow flux decay. These relays are treated the same as a relay with the resistive shunt, using a G_s corresponding to that shown previously for the size of sleeve used on the relay.

Release Time With Contact Protection

Contact life requirements frequently require the use of a capacitor and resistor in shunt with a relay winding, or across a contact that is in series with the relay winding. This changes the rate and character of the flux decay and consequently the release time. The effect is the same whether the protection is in parallel with the relay winding or across the series contacts. In either case, the opening of the circuit starts the collapse of the flux in the relay and causes a flow of current in the capacitor circuit. This current may or may not be oscillatory, depending on the coil turns, coil resistance, and the values of the protective network. The effect of protection on the operate time is minor and can be neglected.

The maximum release time for the AF relay with different ampere turn release values has been plotted for $N^2C \times 10^{-6}$ in Fig. VII-15. These values are for a value of $CR_T = 100$ where C is the protective capacity in microfarads and R_T is the sum of the coil and protective resistances. These times are for the travel to the first contact. For the time to the last contact, add the stagger time of 1 msec for short travel and 1.5 msec for intermediate travel. The release times must be adjusted if the value of CR_T is other than 100. This correction is shown in Fig. VII-16.

Other curves show the minimum release time for the AF relay and the maximum and minimum release times for the AJ relay. The list of the release time curves for protected relays:

Maximum release AF relays	Fig. VII-15

Minimum release	
AF relays	Fig. VII-17
CR_T correction	Fig. VII-16
Maximum release	
AJ relays	Fig. VII-18
Minimum release	
AJ relays	Fig. VII-20
CR_T correction	Fig. VII-19

These curves apply to relays with all stop-disc heights since the release time of protected relays with the same ampere-turn release is independent of the stop-disc height. The release ampere turns, and therefore the release time, for the same spring load will vary with the stop-disc height.

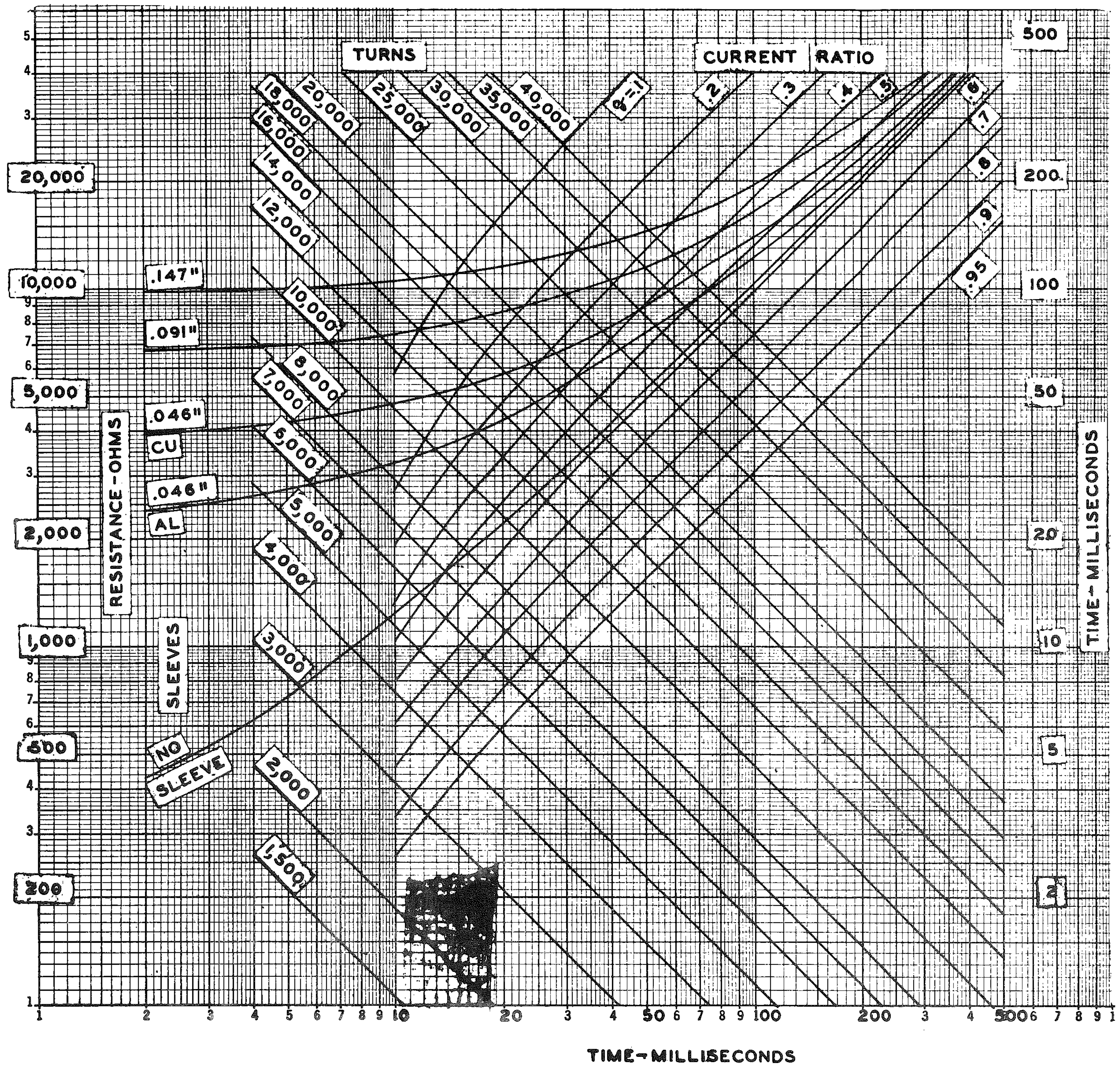
AK Release With Copper Sleeve and Domed Armature

The AK relay may be equipped with a domed armature and a copper sleeve to obtain a slow release time. The minimum release time is obtained by computing the hold ampere turns from data in Section IX and reading the release time from Fig. VII-14B or VII-14C. The maximum release time is obtained in a similar manner using the release value.

Release Time Under Shunt-Down Condition

In case a relay is released by shunting the relay down and the shunt is not of zero resistance, a current will flow in the energizing winding during the releasing period. The releasing time of such a relay can be estimated from the data in this section. The procedure is to determine the coil constant, $G_c = \frac{N^2}{R}$, as described previously. The effect of the current in the short-circuited winding is to increase the release time. This influence can be accounted for by subtracting the ampere turns in the energizing winding during the releasing period from the release ampere turns determined from the hold or release pull curves and using the resulting release ampere turns to determine the release time.

X-75509



FOR AF RELAYS: - USE CURVE AS SHOWN

FOR AG RELAYS: - ADD 20% TO FINAL READINGS

FOR AJ RELAYS: - ADD 10% TO FINAL READINGS

$$t = (1 + X)L(G_c + G_e + G_s)\log_e \frac{1}{1-q}$$

FOR LARGE TIMES (>30 MS.) X = 0.1

FOR SMALL TIMES (10 TO 30 MS.) X VARIES FROM 0.1 TO 0.5

(THESE VALUES ARE INCLUDED IN q CURVES)

$L = .46\mu H$

$G_c = \frac{N^2}{R} 10^{-3}$ KMHOS

$G_e = 5$ KMHOS

$G_s =$
- (210", .147" SLEEVE
- (144", .091" SLEEVE
- (78", .046" SLEEVE, CU.
- (44", .046" SLEEVE. AL.

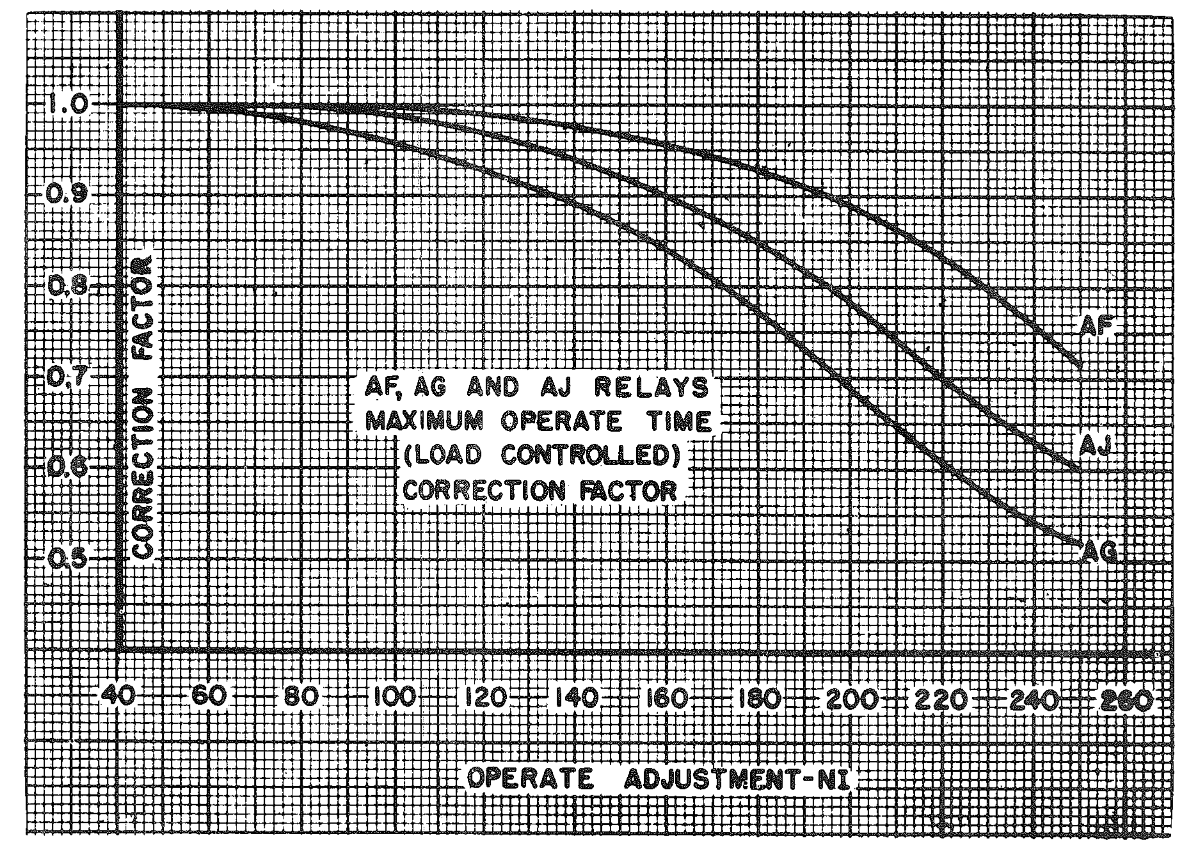


Fig. VII-1 - AF, AG, and AJ Relays - Maximum Operate Time - Load Controlled

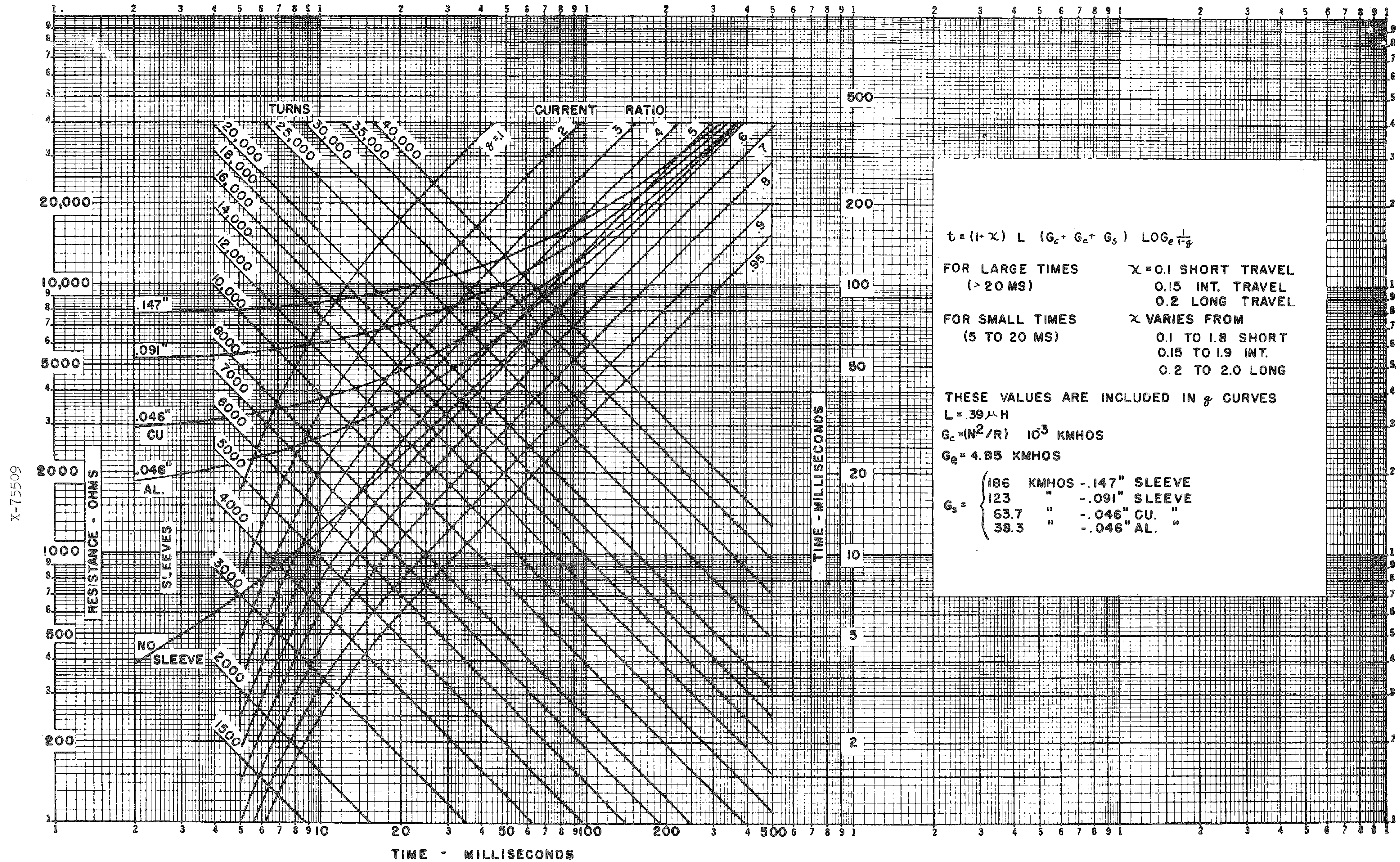


Fig. VII-2 - AF, AG, and AJ Relays - Minimum Operate Time - Load Controlled

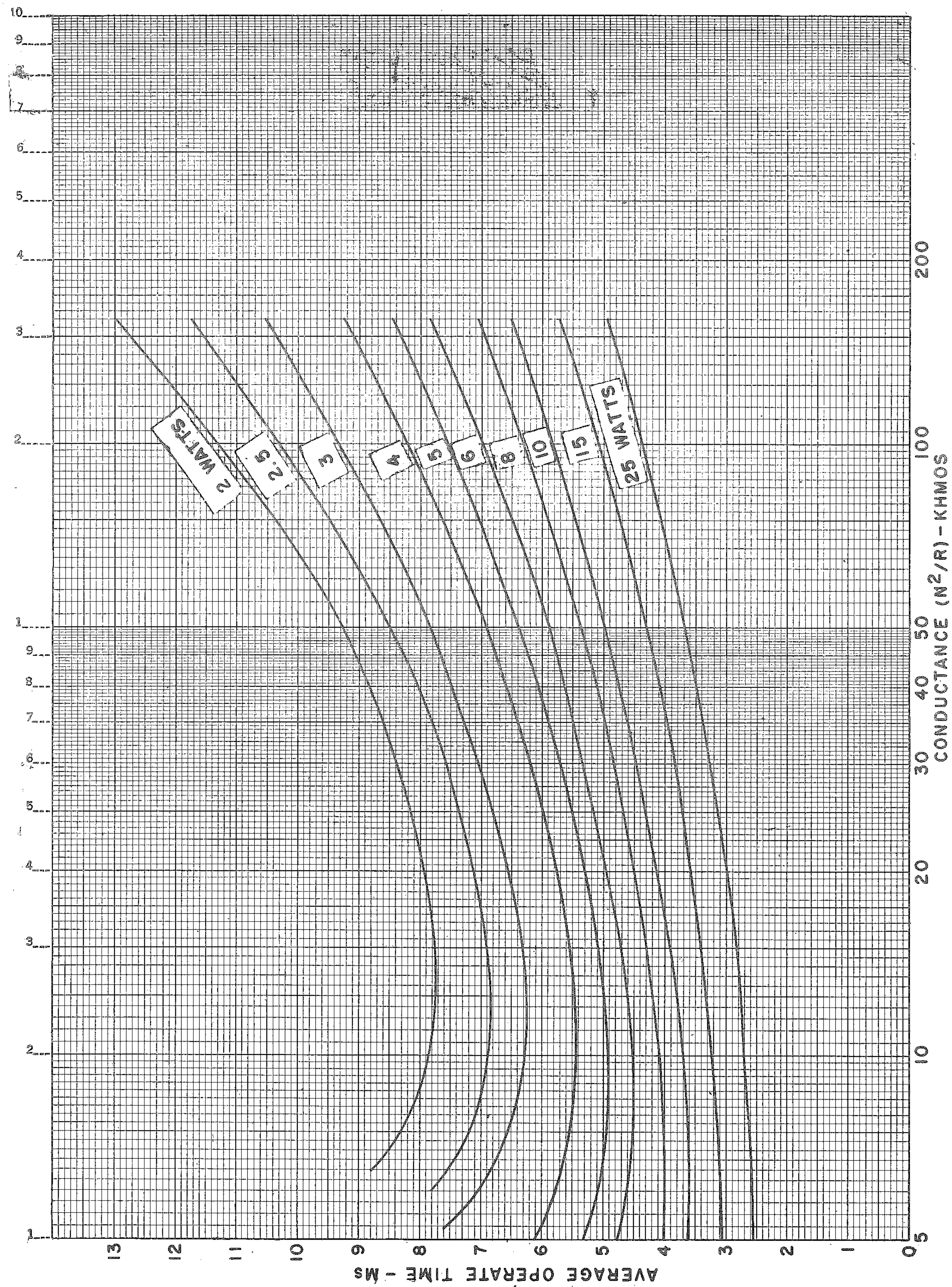


Fig. VII-3 - AF and AJ Relays - Short Armature Travel - Average Operate Time - Mass Controlled

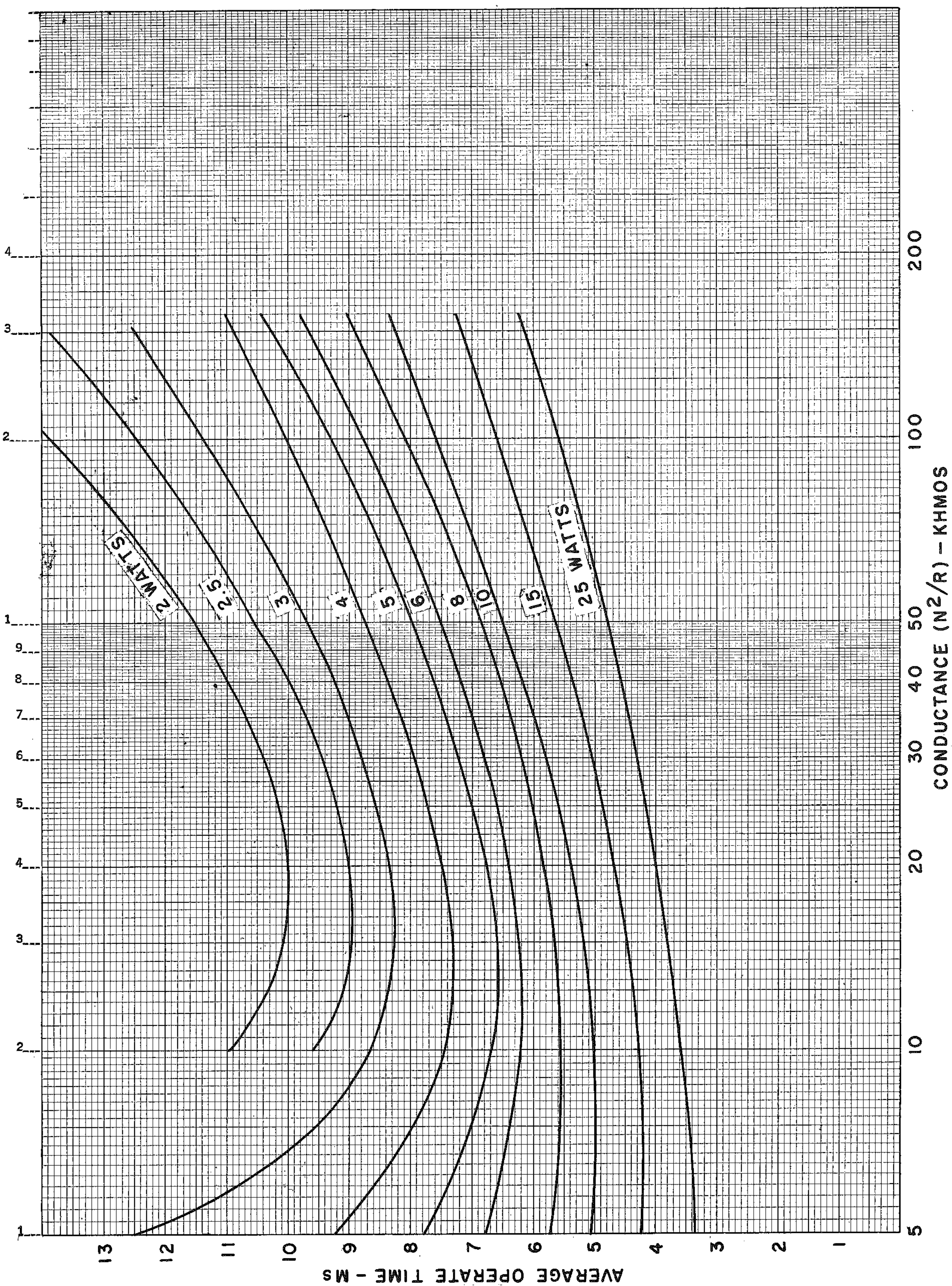
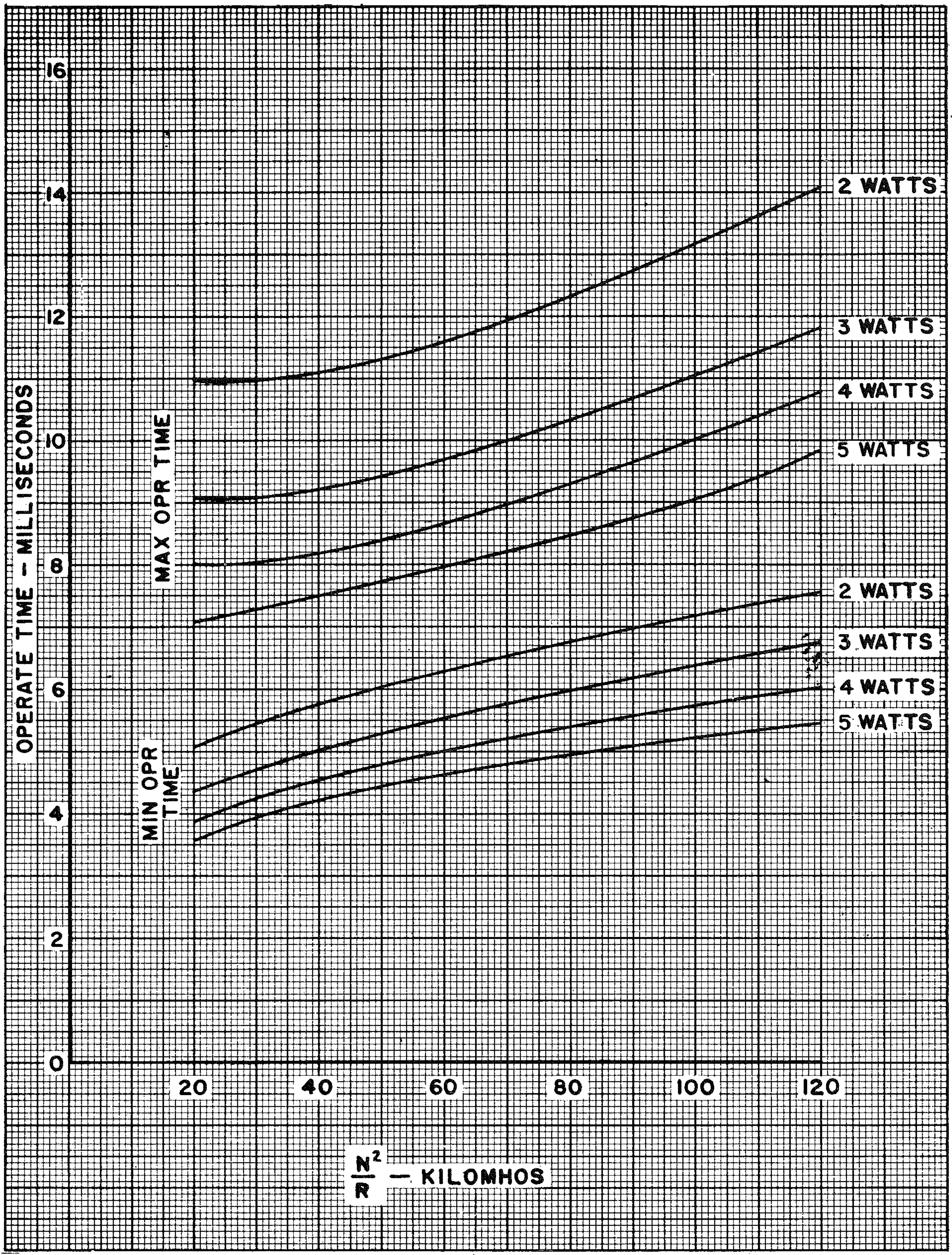


Fig. VII-4 - AF and AJ Relays - Intermediate Armature Travel - Average Operate Time - Mass Controlled



X-75509

Fig. VII-4A - AK Relay Operate Time - Short Travel

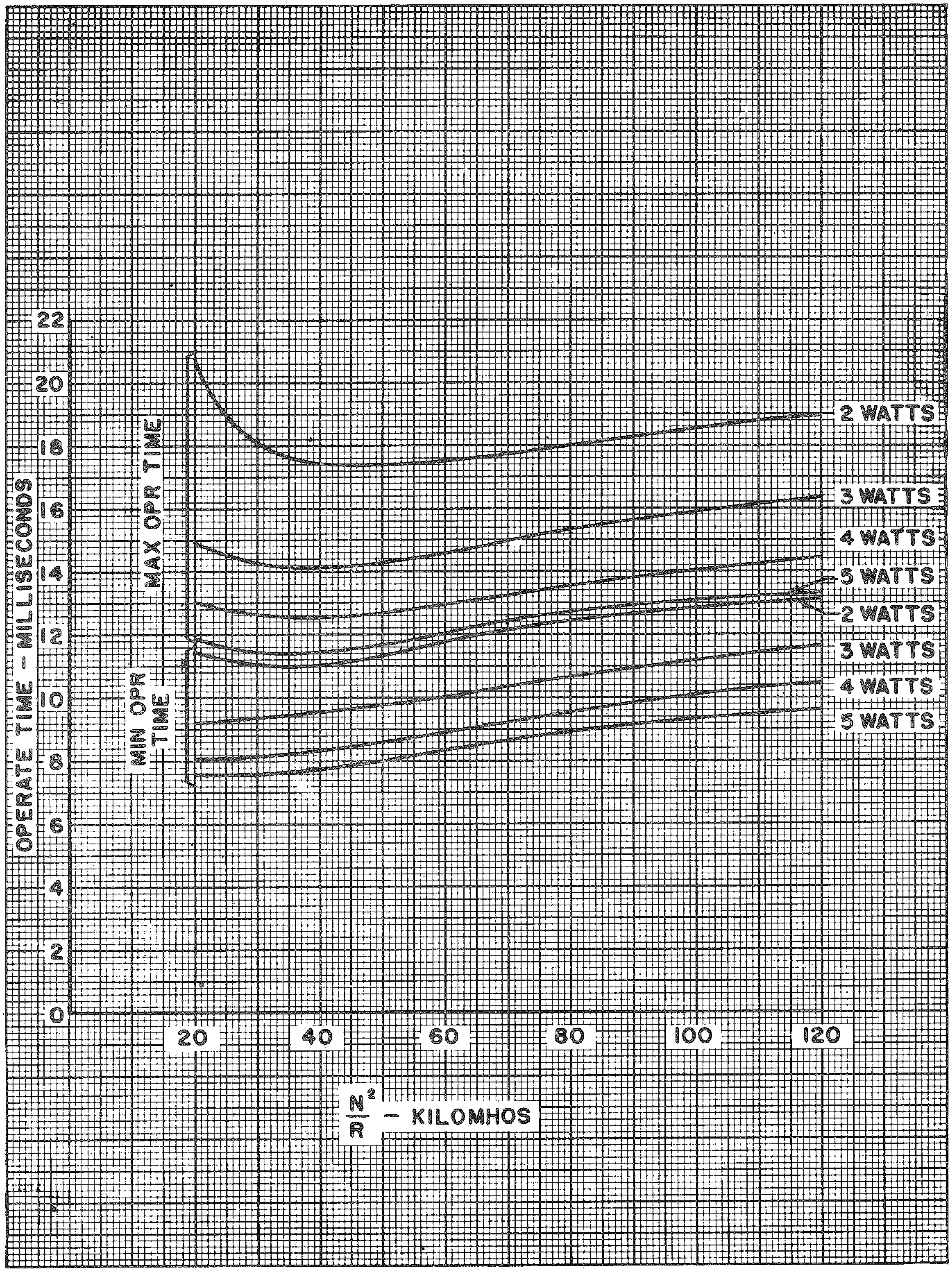


Fig. VII-4B - AK Relay Operate Time - Intermediate Travel

X-75509

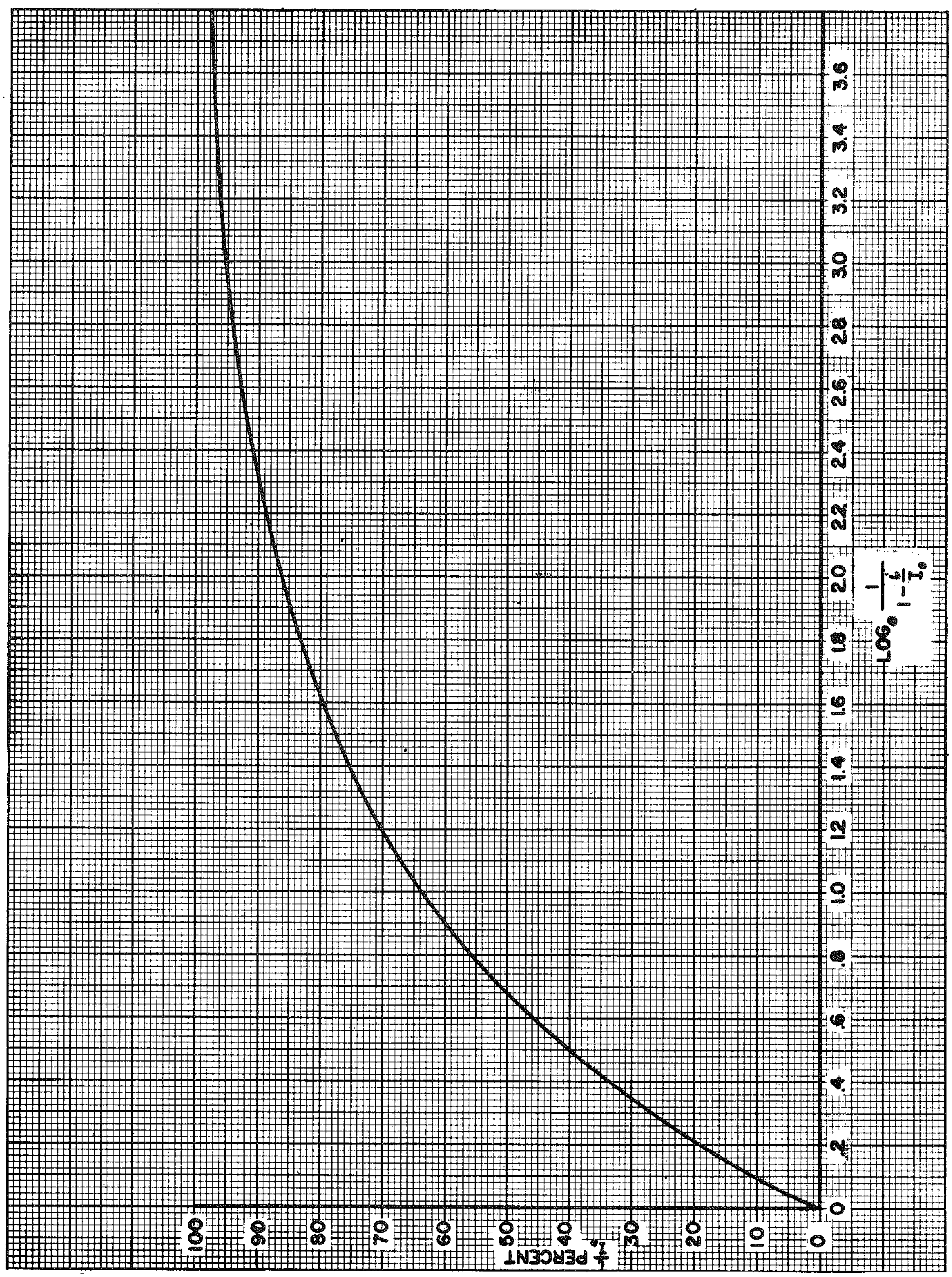


Fig. VII-4C - Time Constant Curve

X-75509

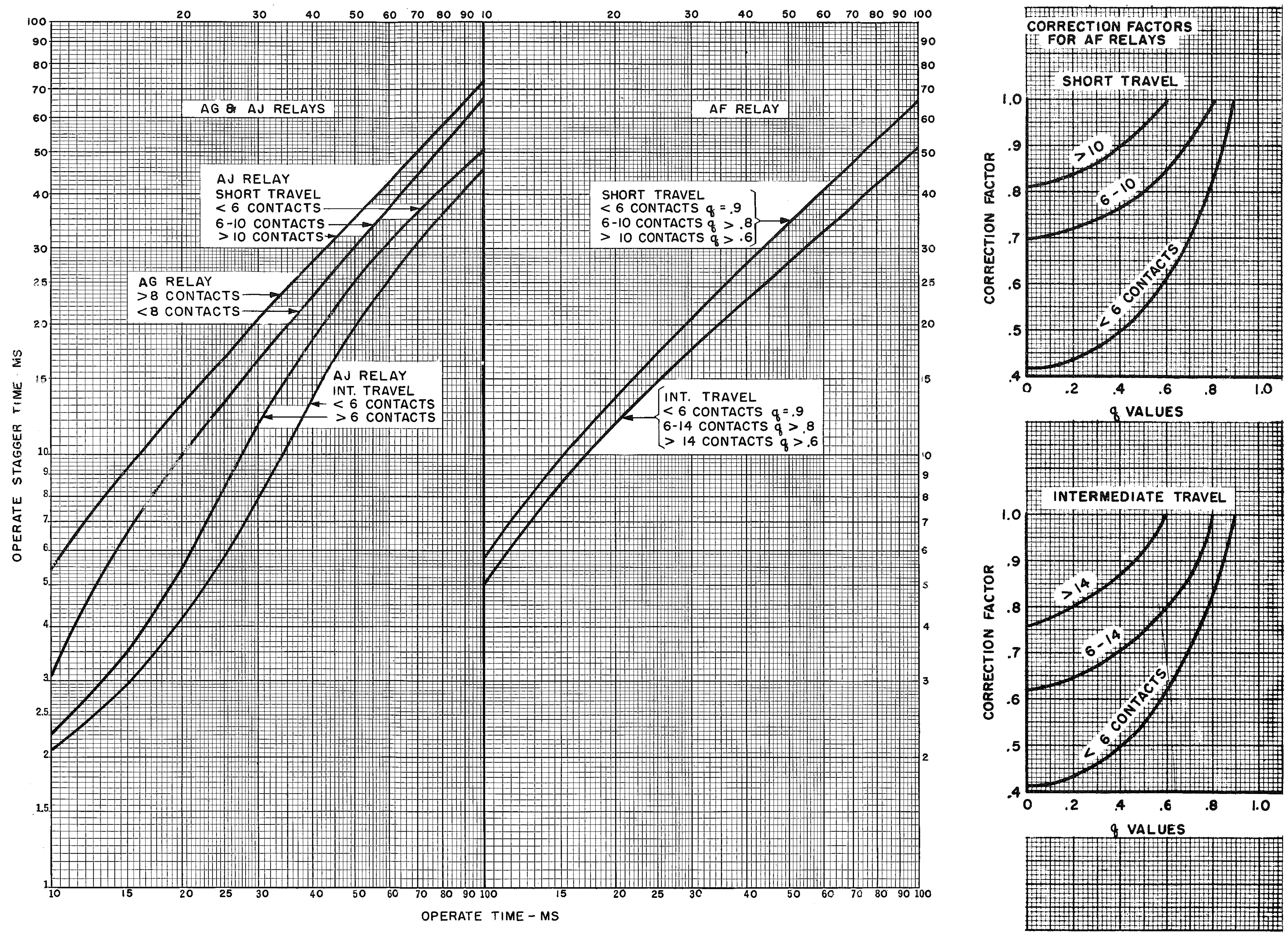


Fig. VII-5 - Load-Controlled Stagger Time

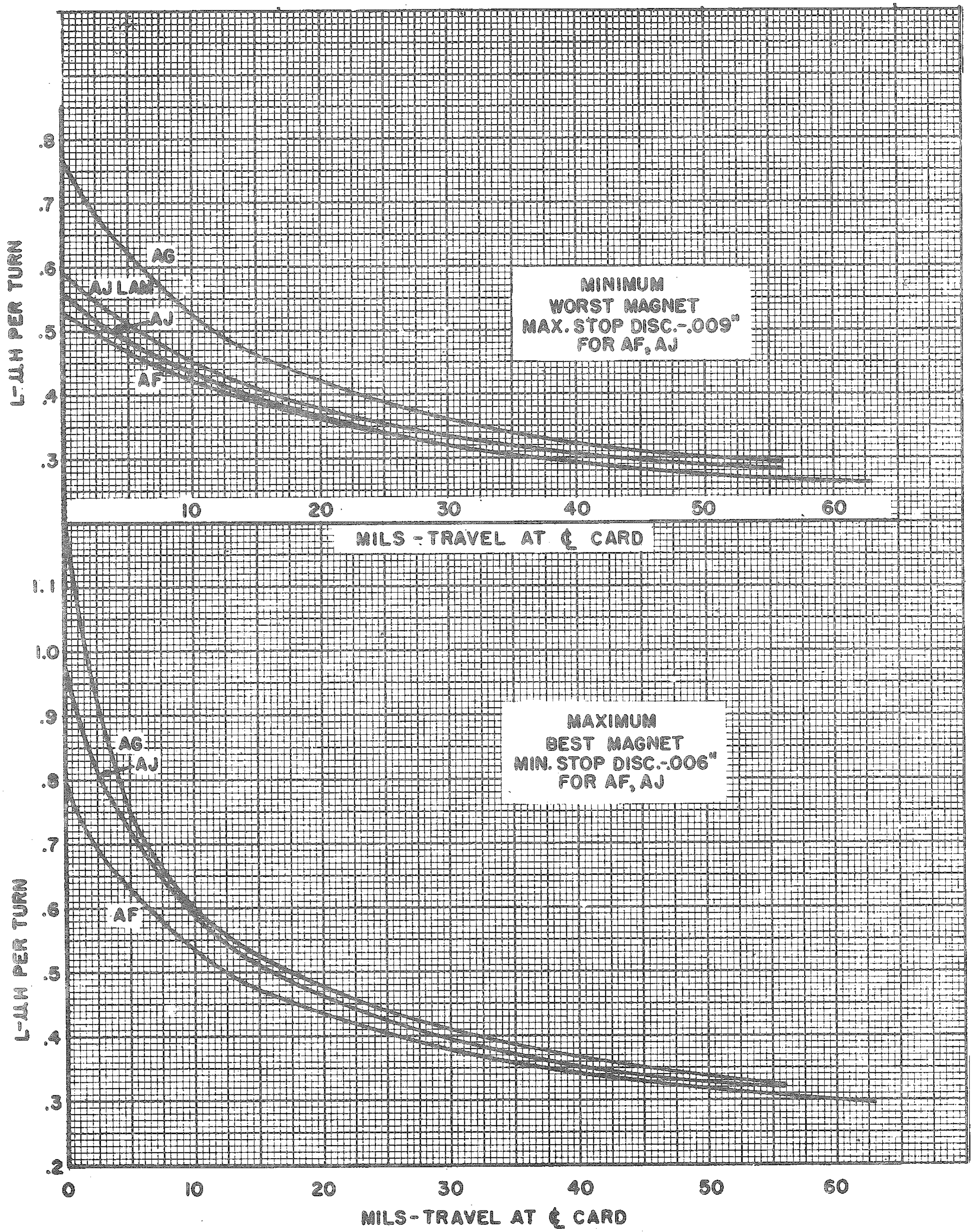


Fig. VII-6 - AF, AG, and AJ Relays - Inductance Constant of One Turn

X-75509

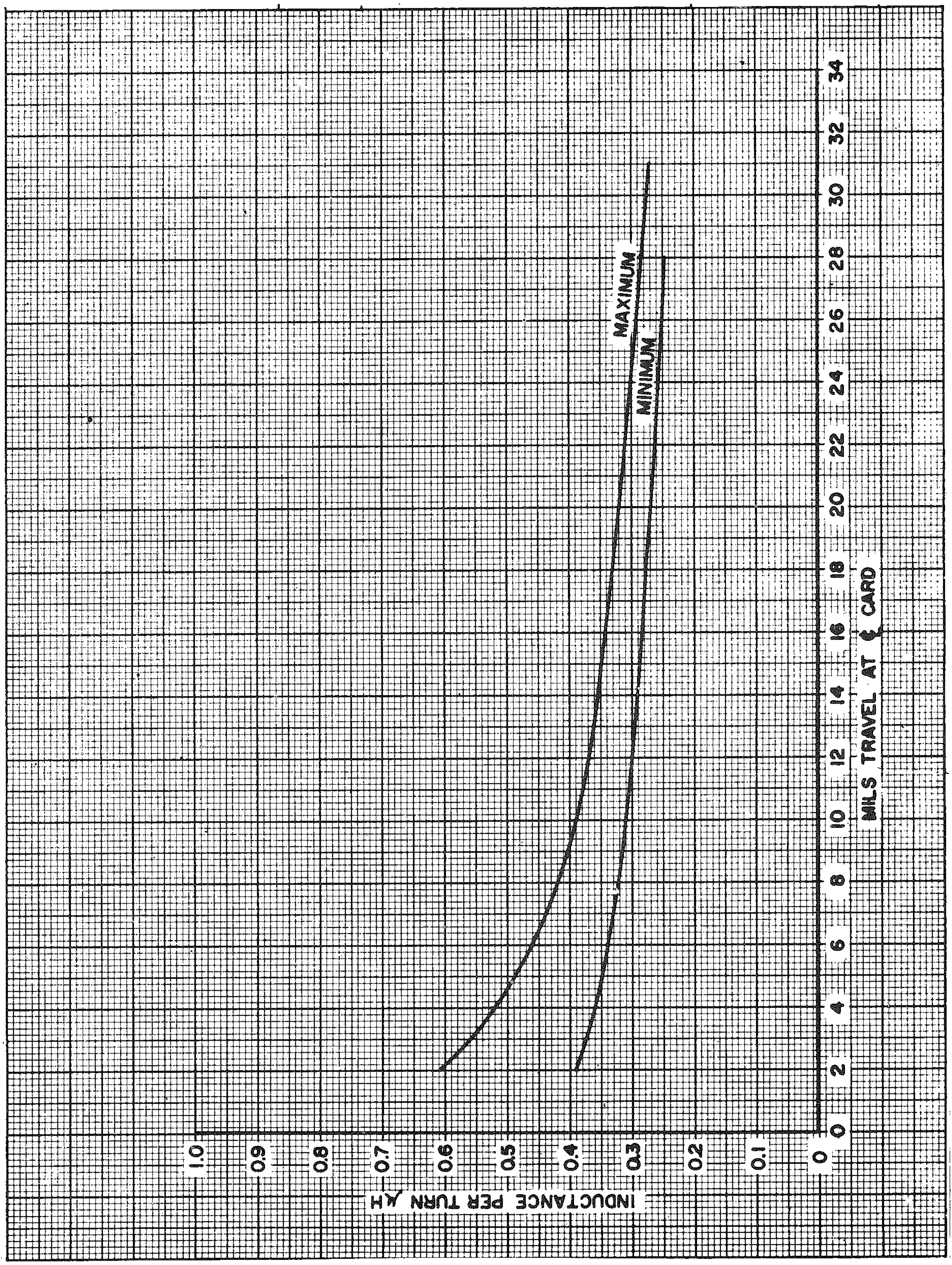
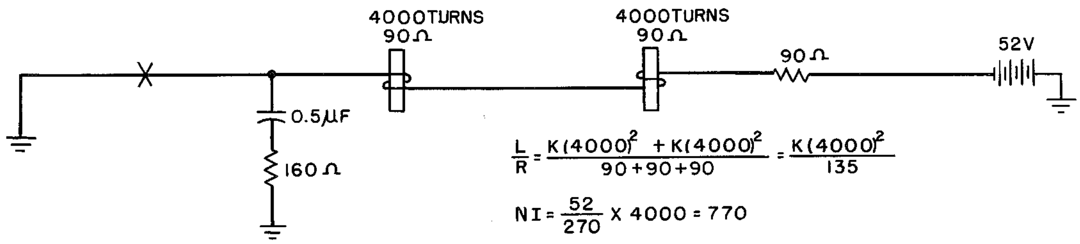


Fig. VII-6A - AK Relay - Inductance Constant of One Turn

CKT. TO BE SIMPLIFIED



$$\frac{L}{R} = \frac{K(4000)^2 + K(4000)^2}{90+90+90} = \frac{K(4000)^2}{135}$$

$$NI = \frac{52}{270} \times 4000 = 770$$

$$rC = 0.5 \times 10^{-6} \times 160 = 80 \times 10^{-6}$$

$$LC = 2 \times K(4000)^2 \times 0.5 \times 10^{-6} = K(4000)^2 \times 10^{-6}$$

FIG. VII-7a

EQUIVALENT CKTS.

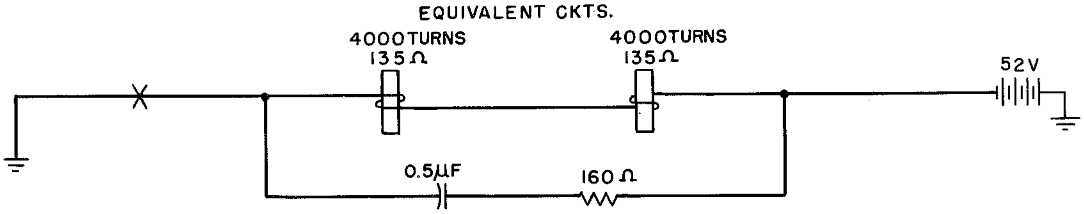


FIG. VII-7b

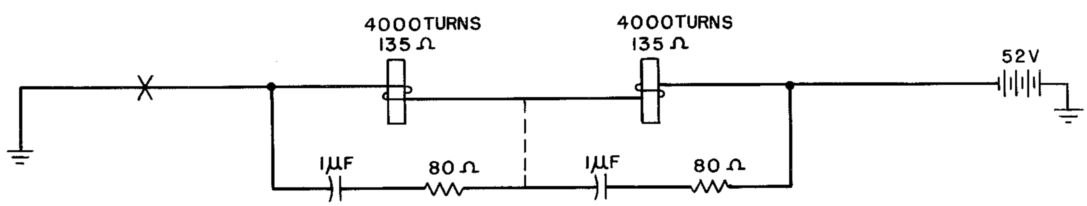
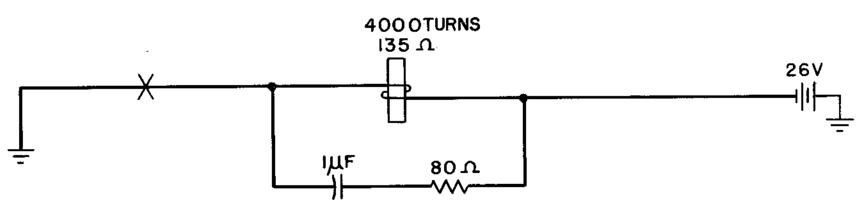


FIG. VII-7c



$$\frac{L}{R} = \frac{K(4000)^2}{135}$$

$$NI = \frac{26}{135} \times 4000 = 770$$

$$rC = 1 \times 10^{-6} \times 80 = 80 \times 10^{-6}$$

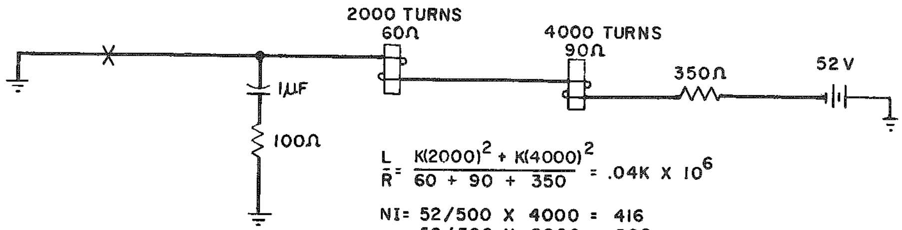
$$LC = K(4000)^2 \times 10^{-6}$$

FIG. VII-7d

Fig. VII-7 - Equivalent Circuits

X-75509

CIRCUIT TO BE SIMPLIFIED



$$\frac{L}{R} = \frac{K(2000)^2 + K(4000)^2}{60 + 90 + 350} = .04K \times 10^6$$

$$NI = 52/500 \times 4000 = 416$$
$$= 52/500 \times 2000 = 208$$

$$rC = 100 \times 1 \times 10^{-6} = 100 \times 10^{-6}$$

$$LC = (K(2000)^2 + K(4000)^2) \times 1 \times 10^{-6} = 20K$$

FIGURE VII-8A

EQUIVALENT CIRCUITS

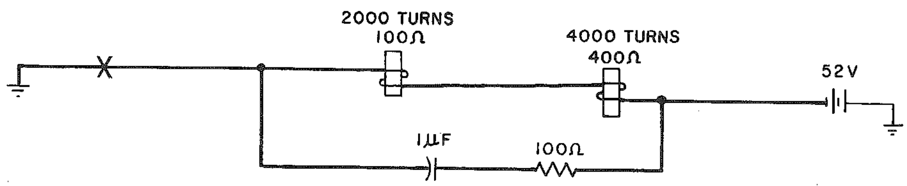


FIGURE VII-8B

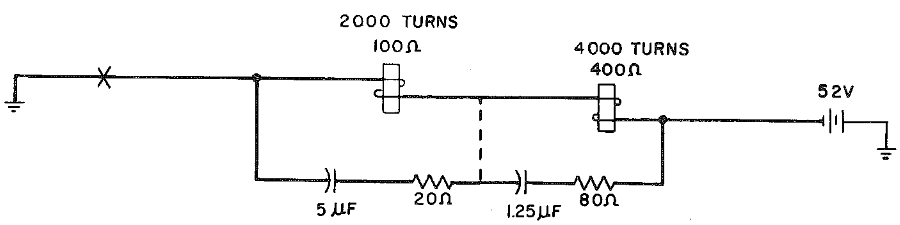


FIGURE VII-8C

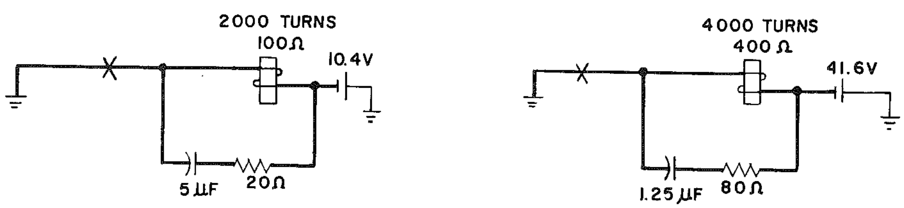


FIGURE VII-8D

$$\frac{L}{R} = \frac{K(2000)^2}{100} = .04K \times 10^6$$

$$NI = \frac{10.4}{100} \times 2000 = 208$$

$$rC = 5 \times 10^{-6} \times 20 = 100 \times 10^{-6}$$

$$LC = K(2000)^2 \times 5 \times 10^{-6} = 20K$$

$$\frac{L}{R} = \frac{K(4000)^2}{400} = .04K \times 10^6$$

$$NI = \frac{41.6}{400} \times 4000 = 416$$

$$rC = 1.25 \times 10^{-6} \times 80 = 100 \times 10^{-6}$$

$$LC = K(4000)^2 \times 1.25 \times 10^{-6} = 20K$$

Fig. VII-8 - Equivalent Circuits

CKT. TO BE SIMPLIFIED

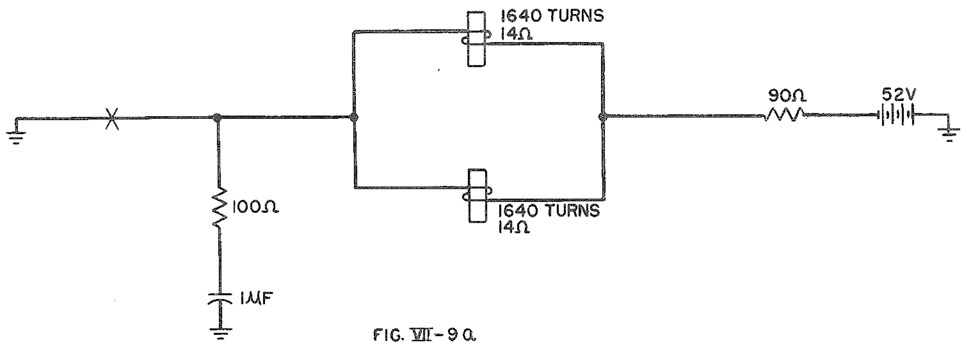


FIG. VII-9a

EQUIVALENT CKTS.

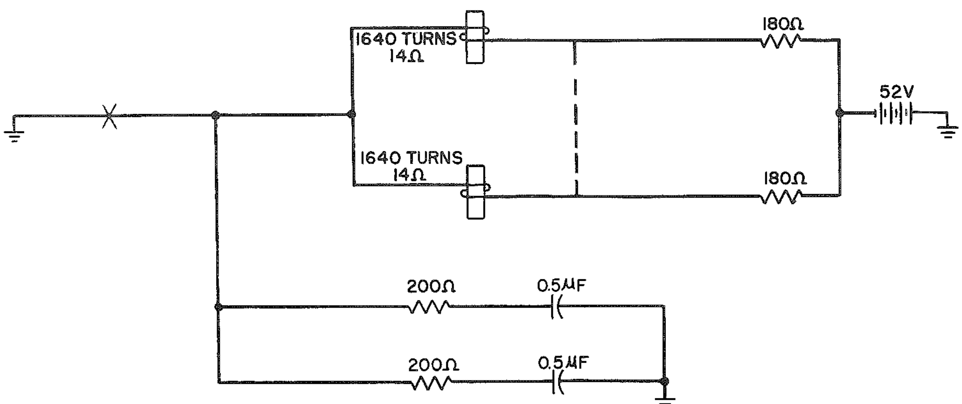


FIG. VII-9b

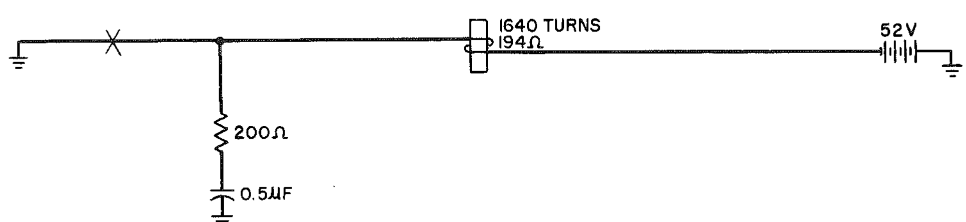


FIG. VII-9C

X-75509

Fig. VII-9 - Equivalent Circuits

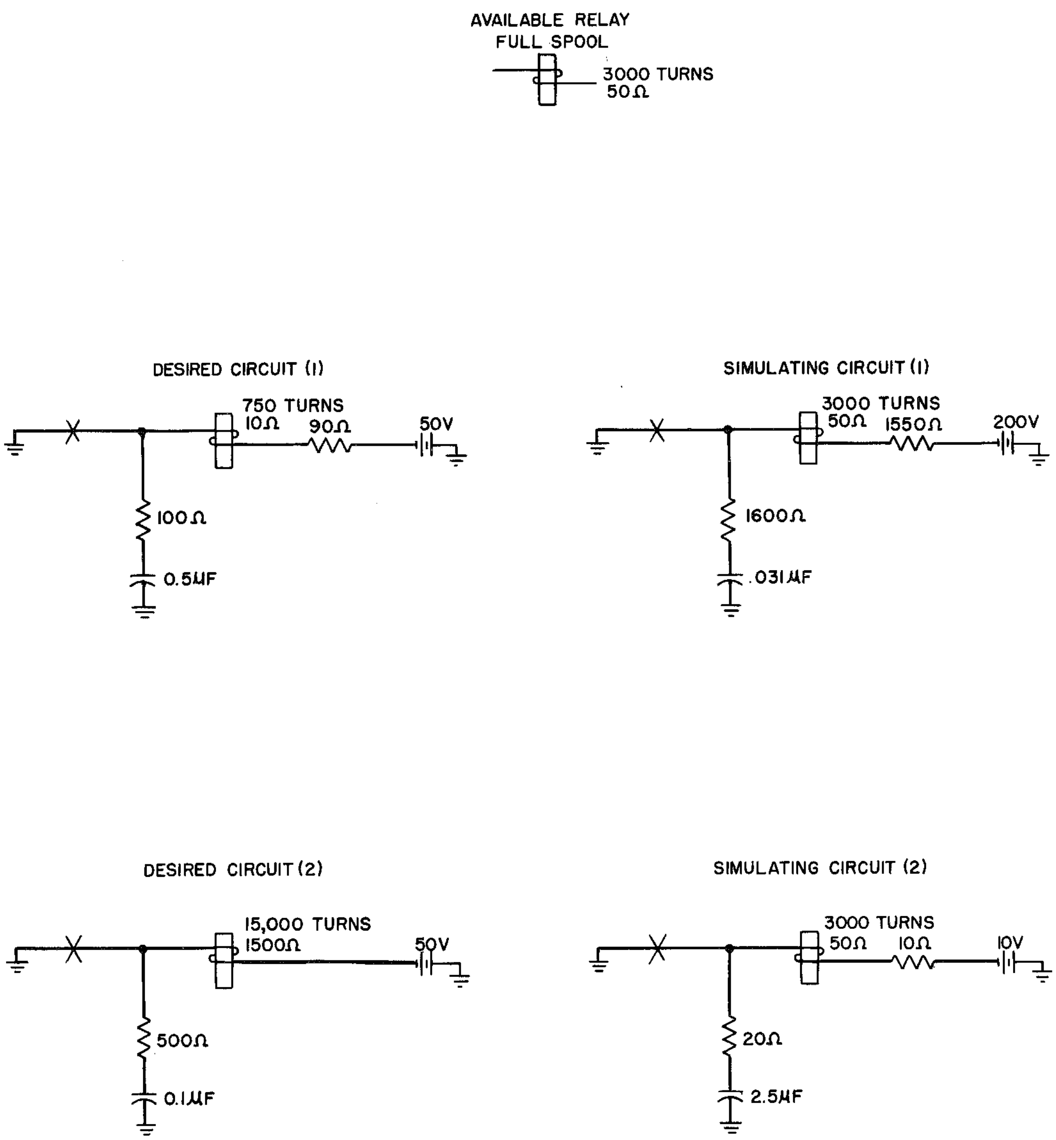
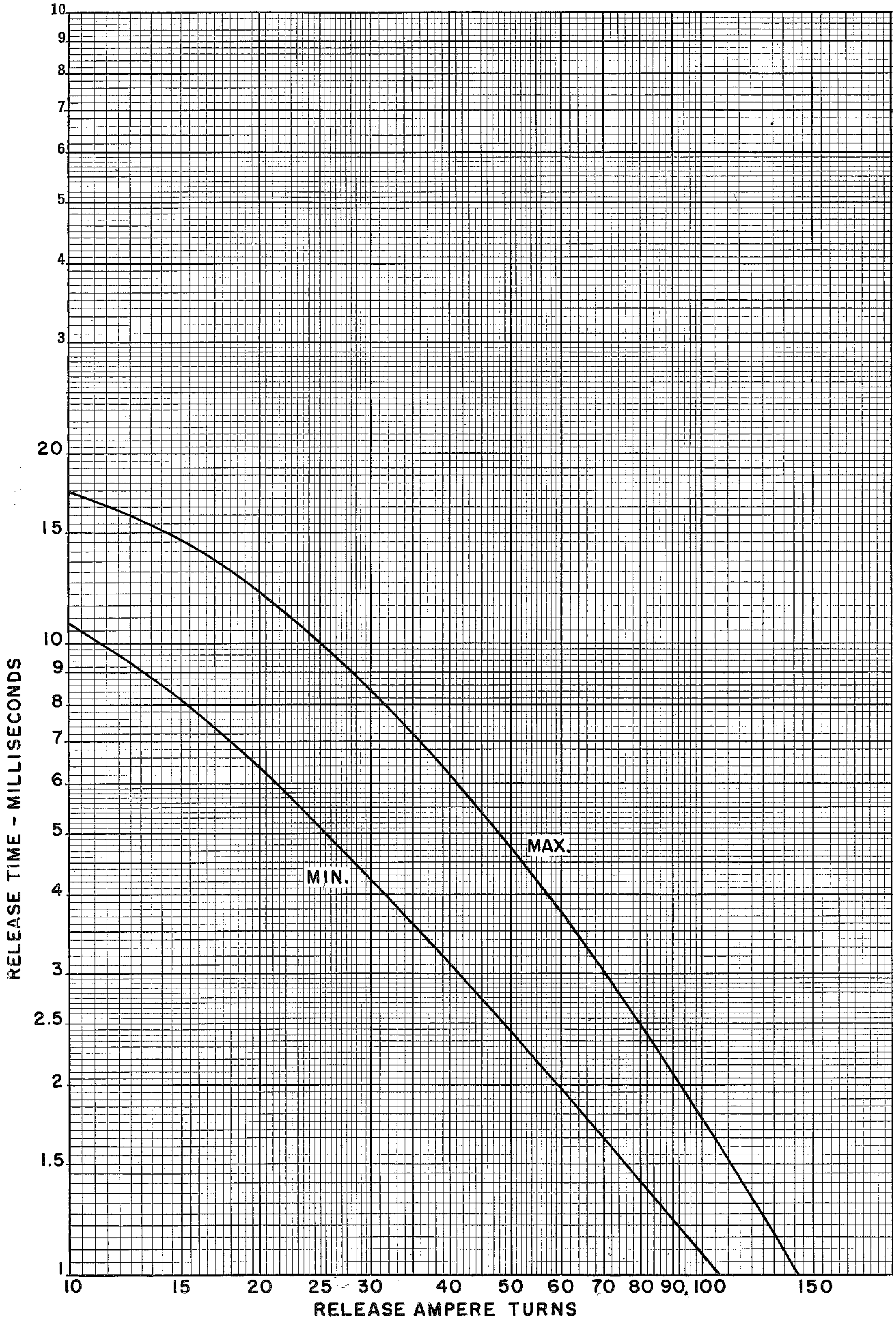


Fig. VII-10 - Equivalent Circuits



X-75509

Fig. VII-11 - AF and AJ Relays - Open Circuit Release - No Sleeve or Contact Protection (0.006-Inch Stop Discs)

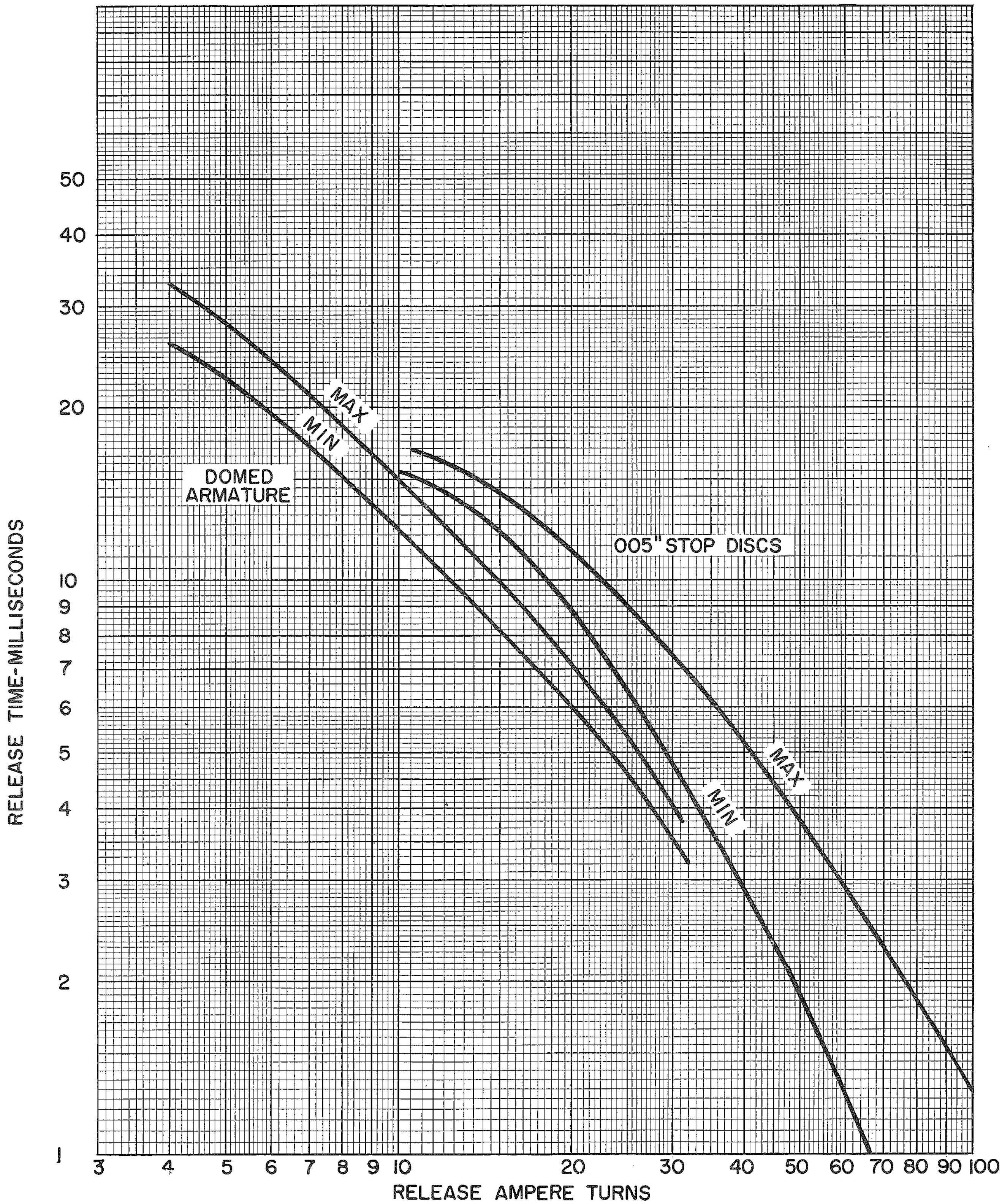
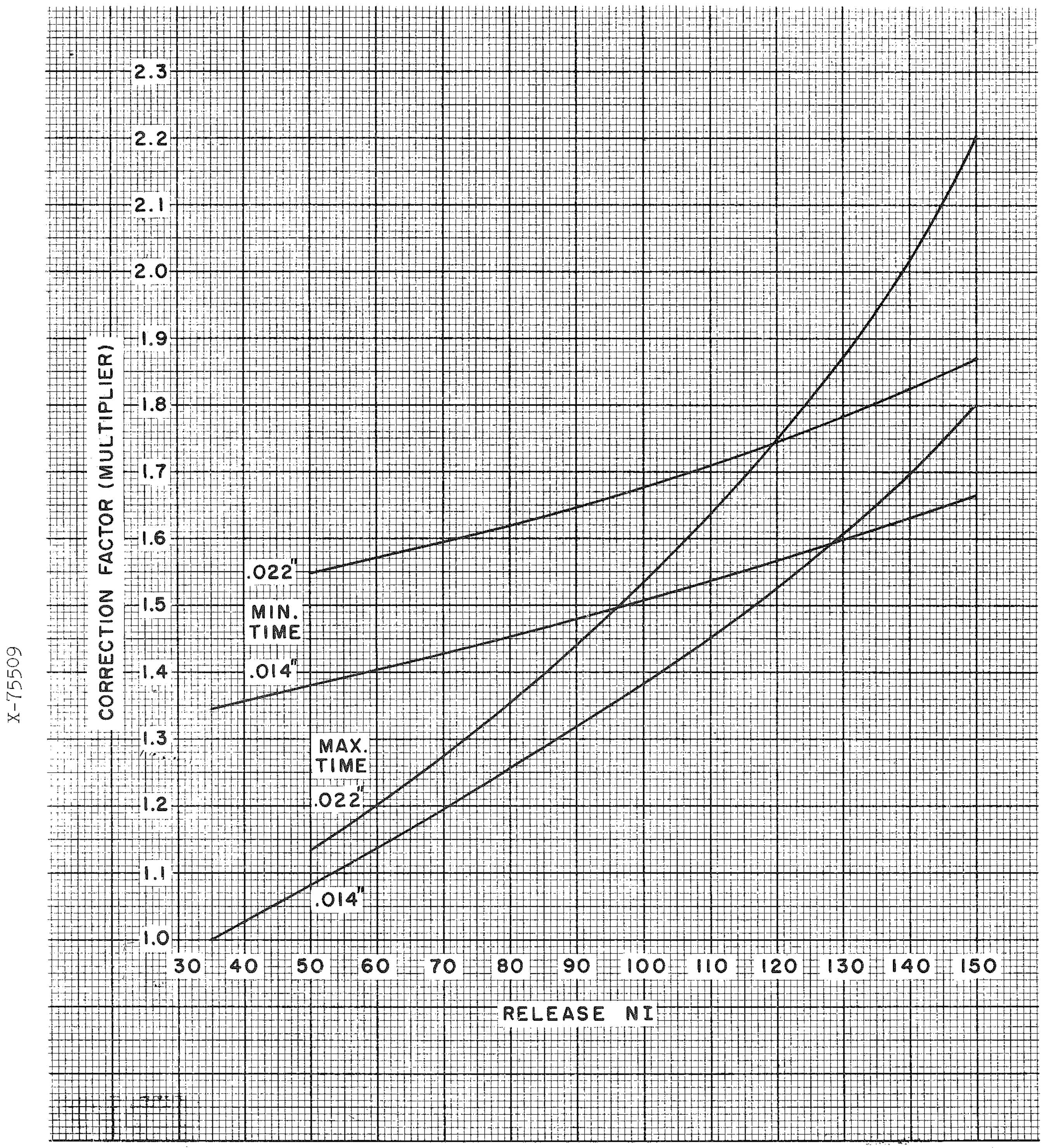


Fig. VII-11A - AK Relay - Open Circuit Release Time -
No Sleeve or Contact Protection



STOP DISC CORRECTION
OPEN CIRCUIT OR SHUNT RELEASE

Fig. VII-12 - Stop Disc Correction - No Contact Protection

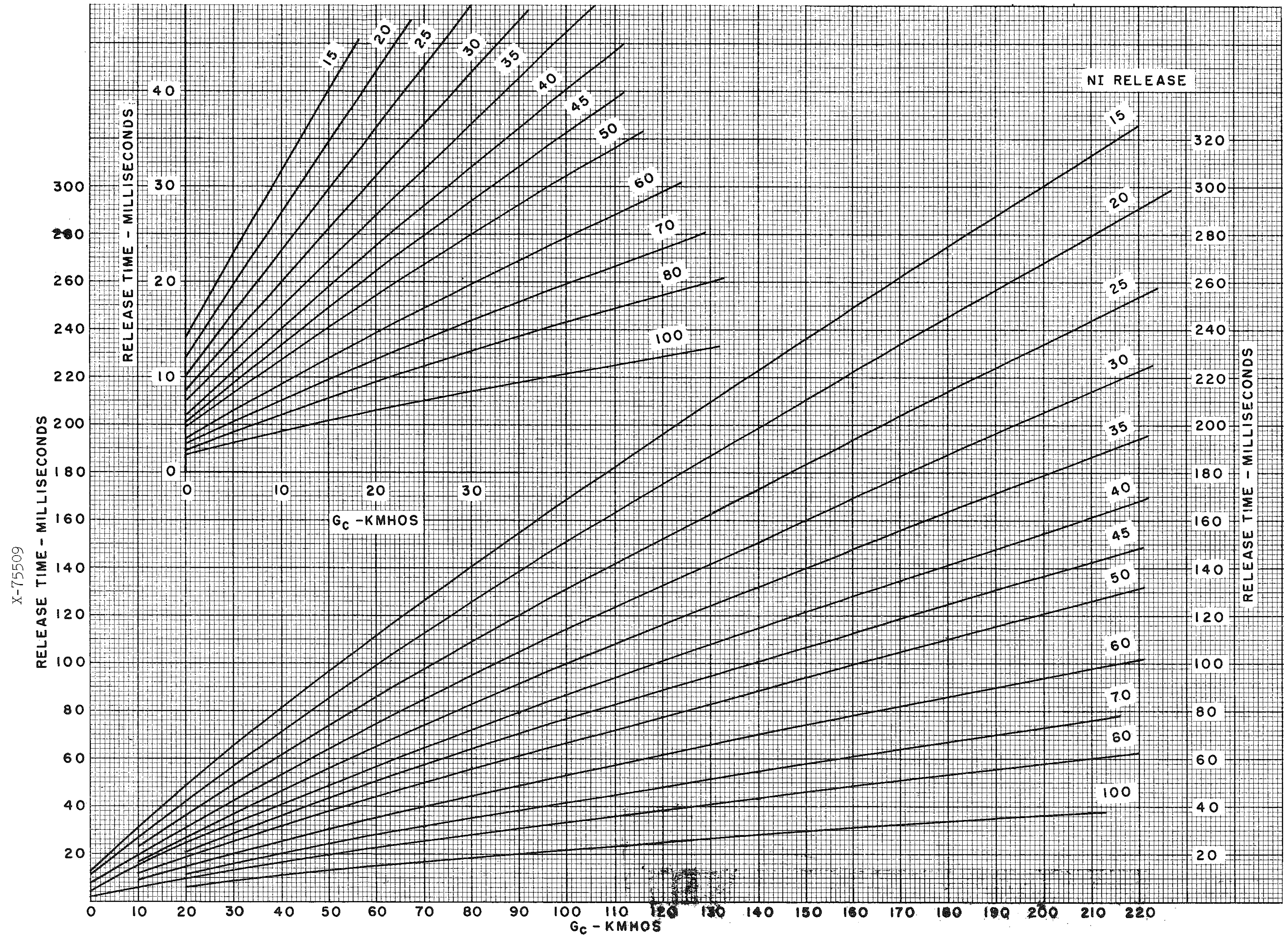
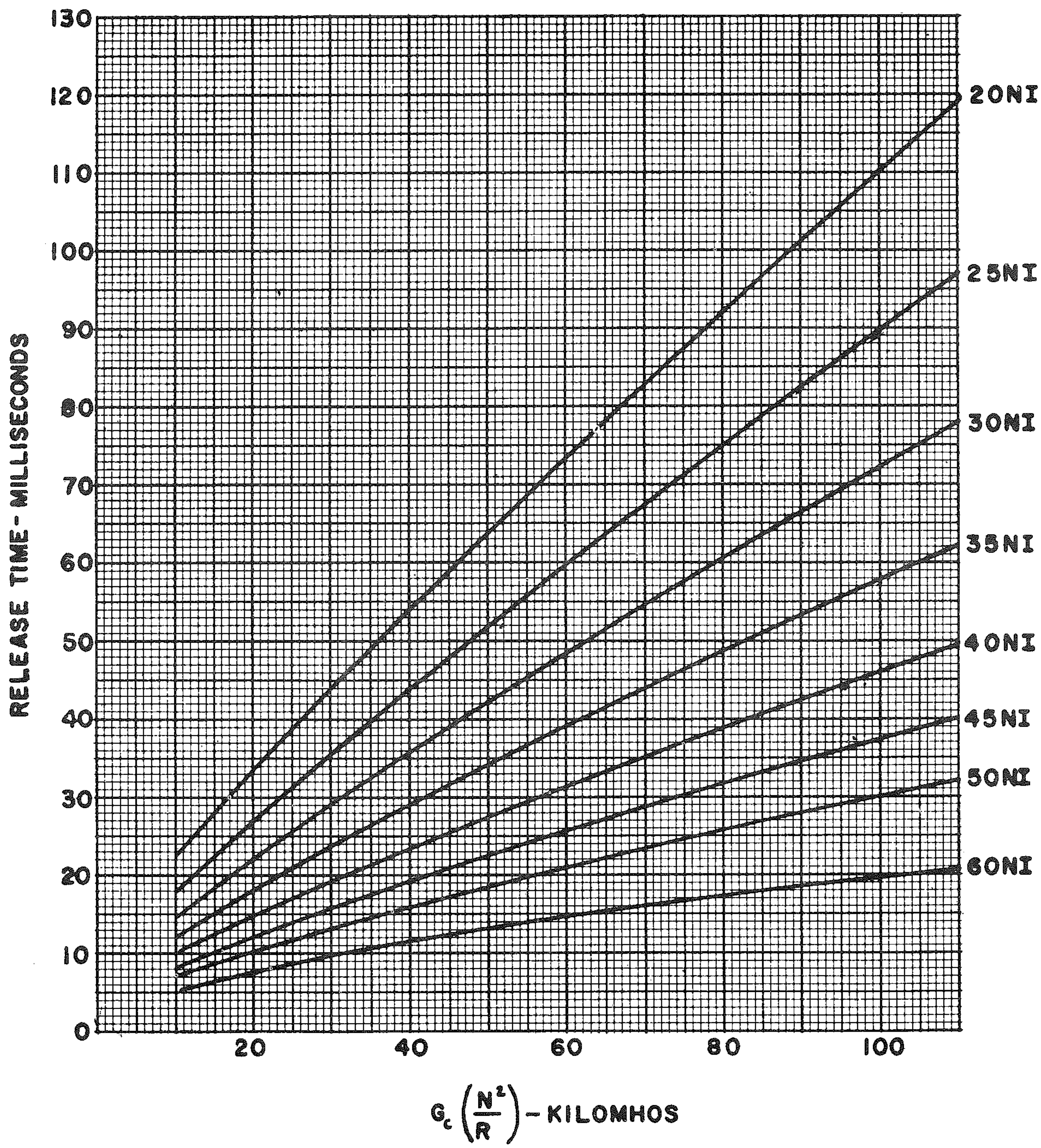


Fig. VII-13 - AF and AJ Relays - Maximum Release Time With Resistive Shunt



X-75509

Fig. VII-13A - AK Relay - Maximum Release Time With Resistive Shunt

X-75509

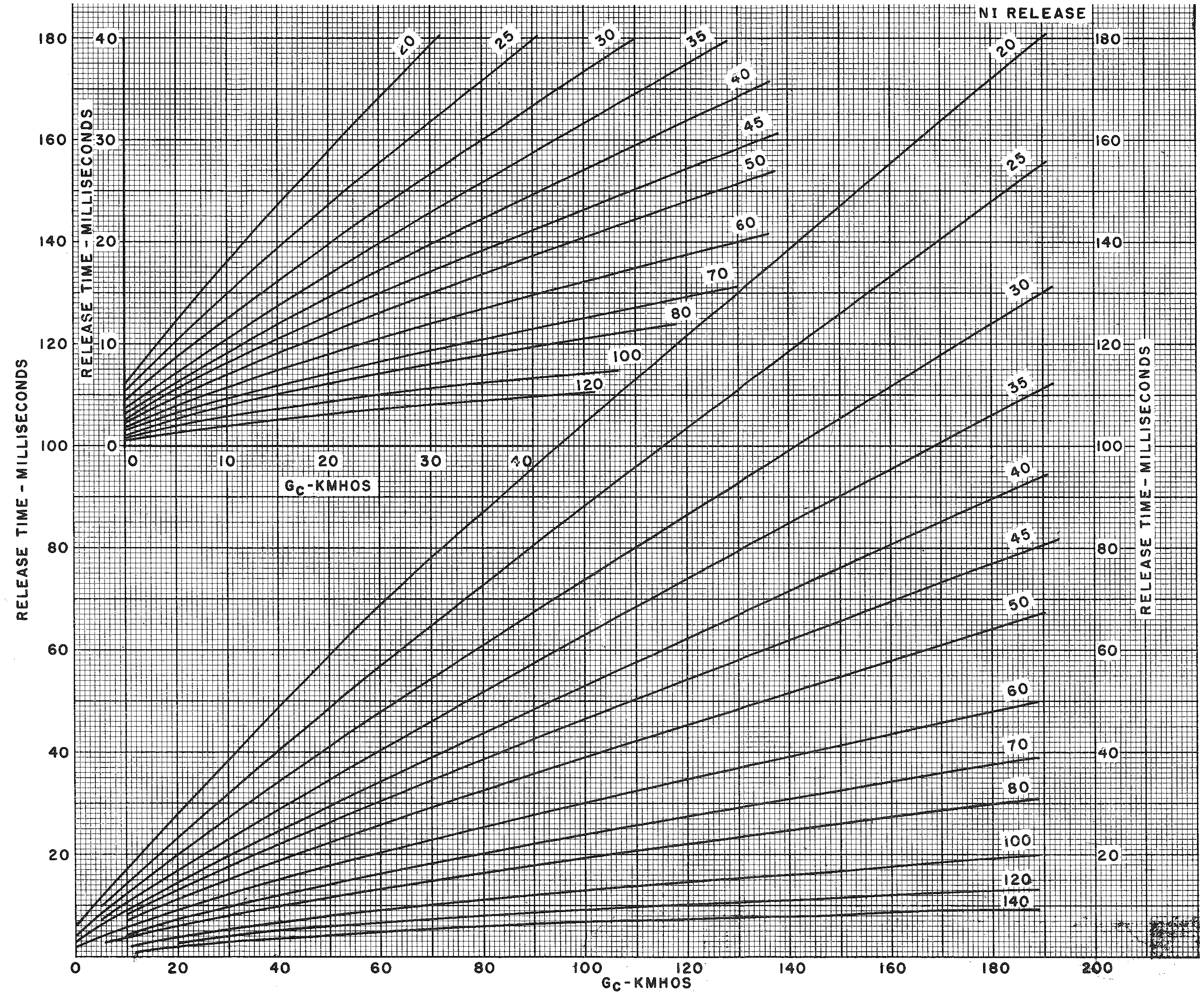
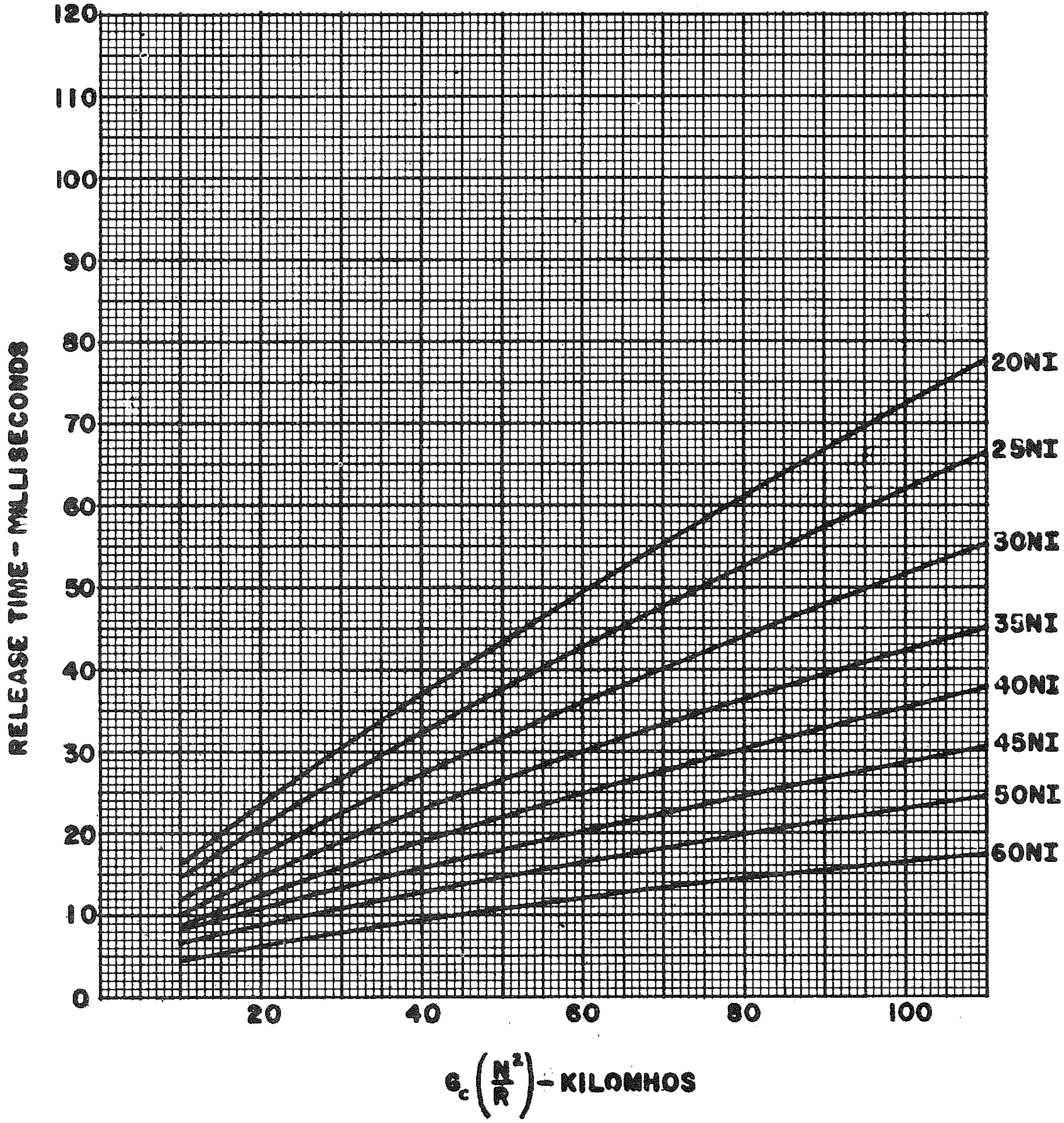


Fig. VII-14 - AF and AJ Relays - Minimum Release Time With Resistive Shunt



X-75509

Fig. VII-14A - AK Relay - Minimum Release Times With Resistive Shunt

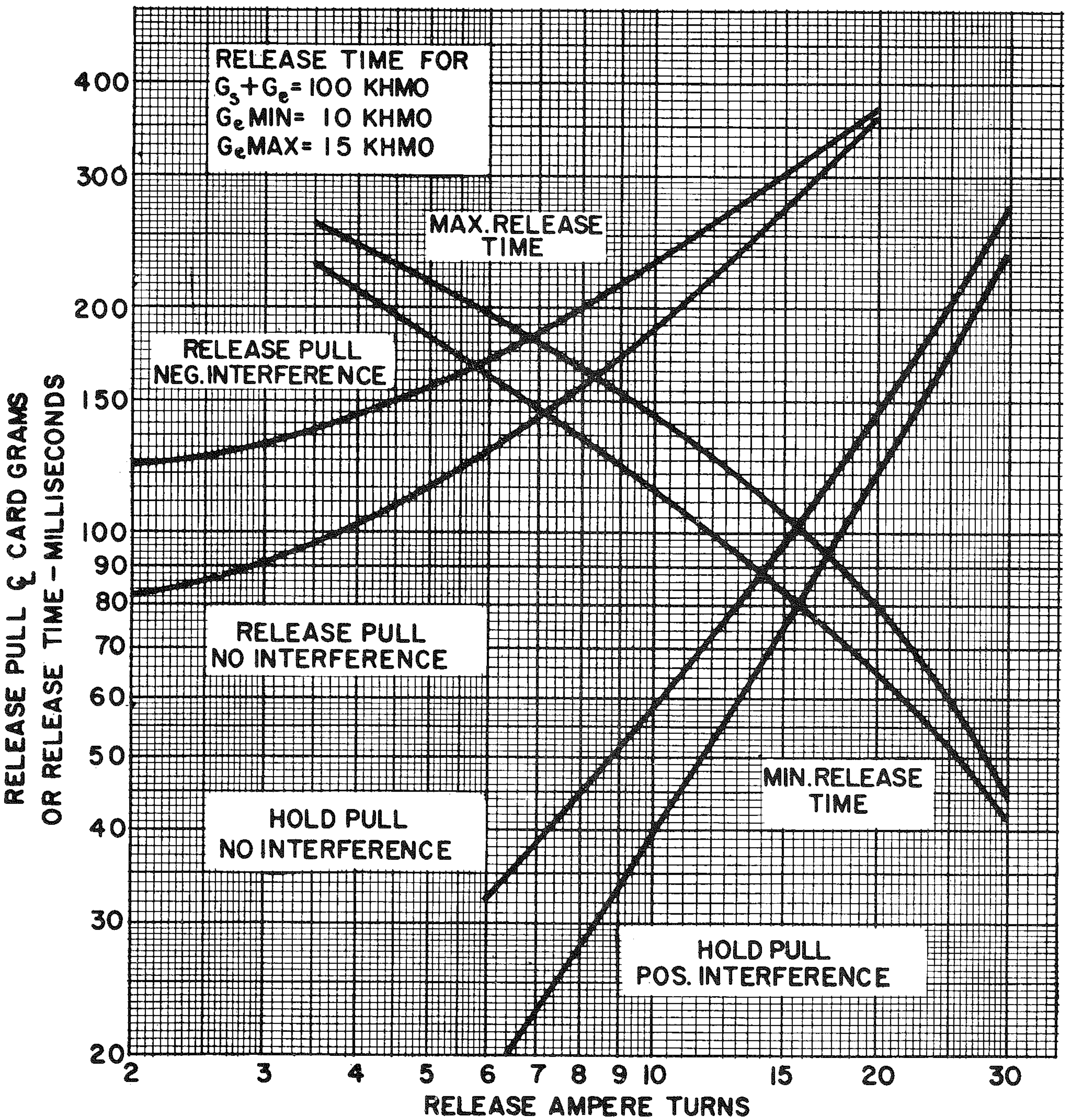


Fig. VII-14B - AK Relays - Release Time - Domed Armature With Shunt
Positive Interference: Both Coils Same Polarity
Negative Interference: Coils Oppositely Poled

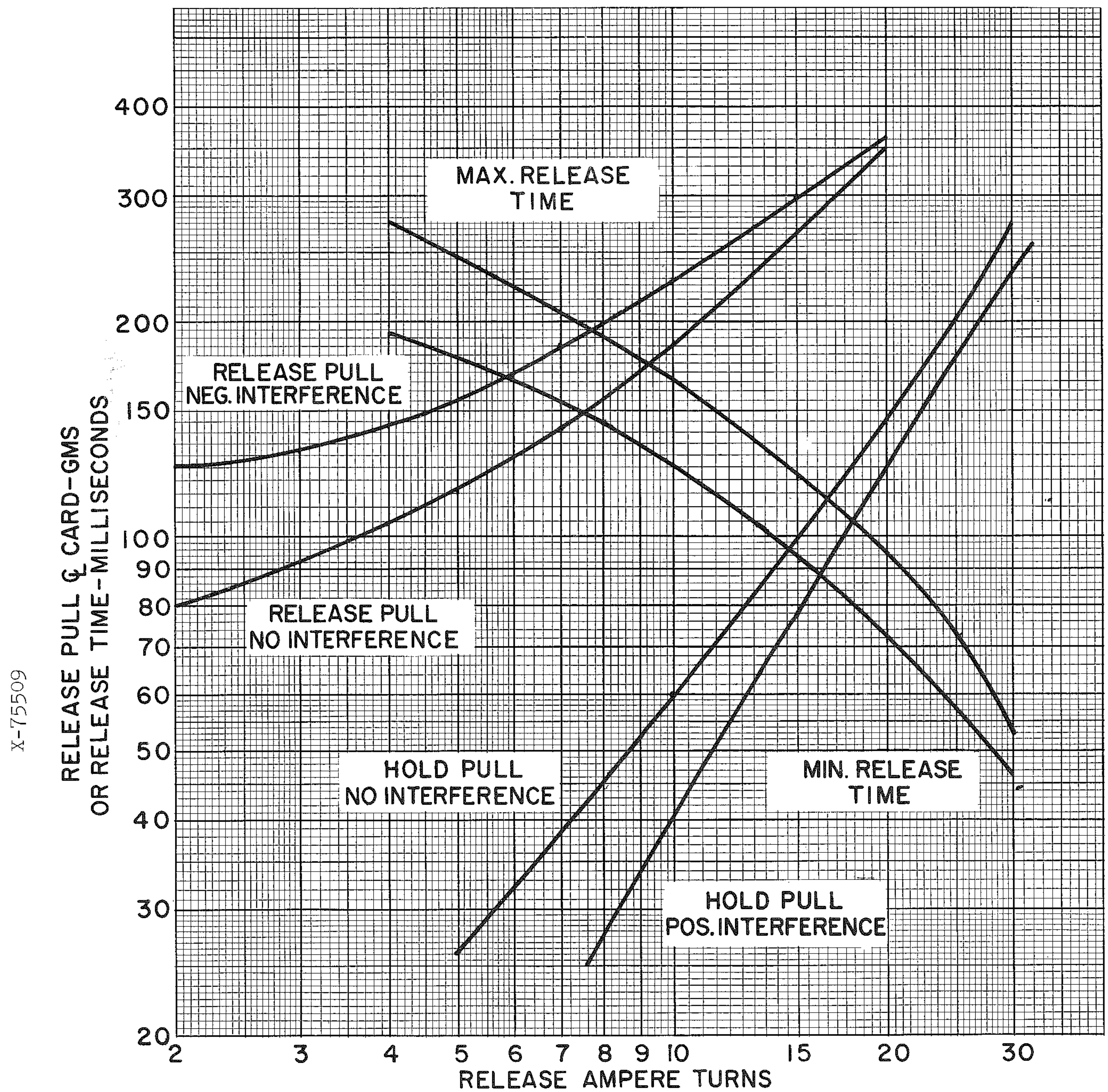


Fig. VII-14C - AK Relay - Slow Release - 0.069-Inch Copper Sleeve
(Domed Armature)

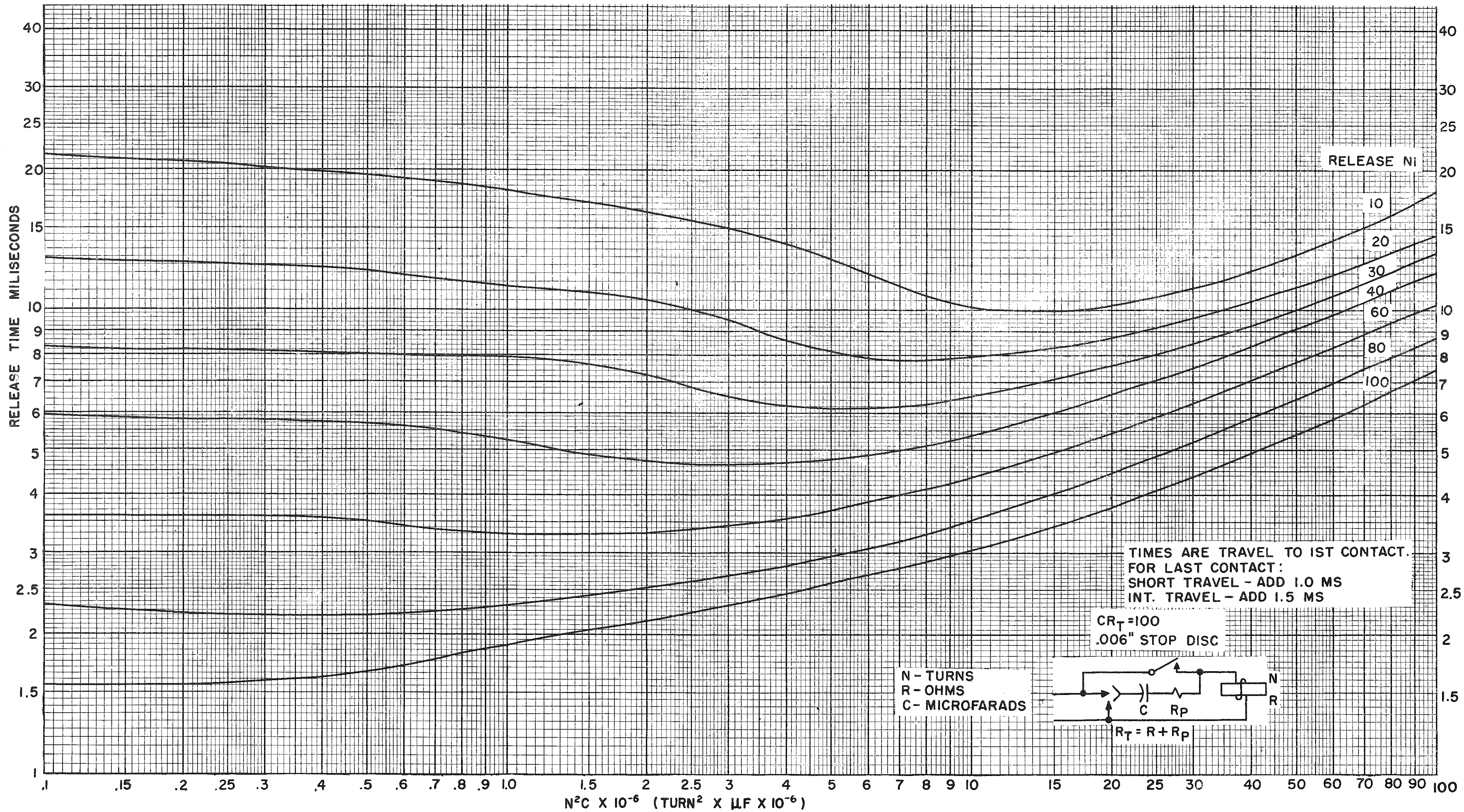
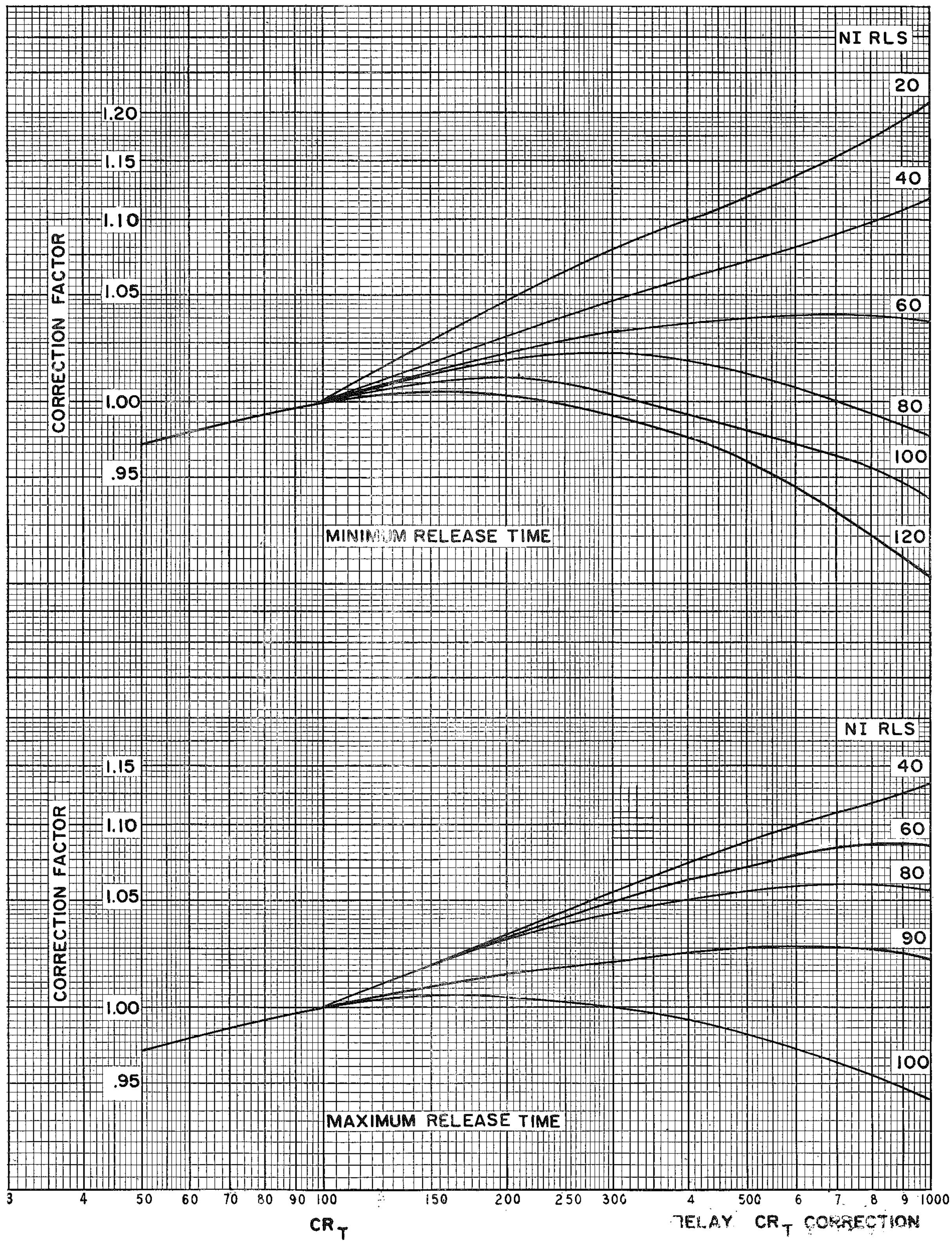
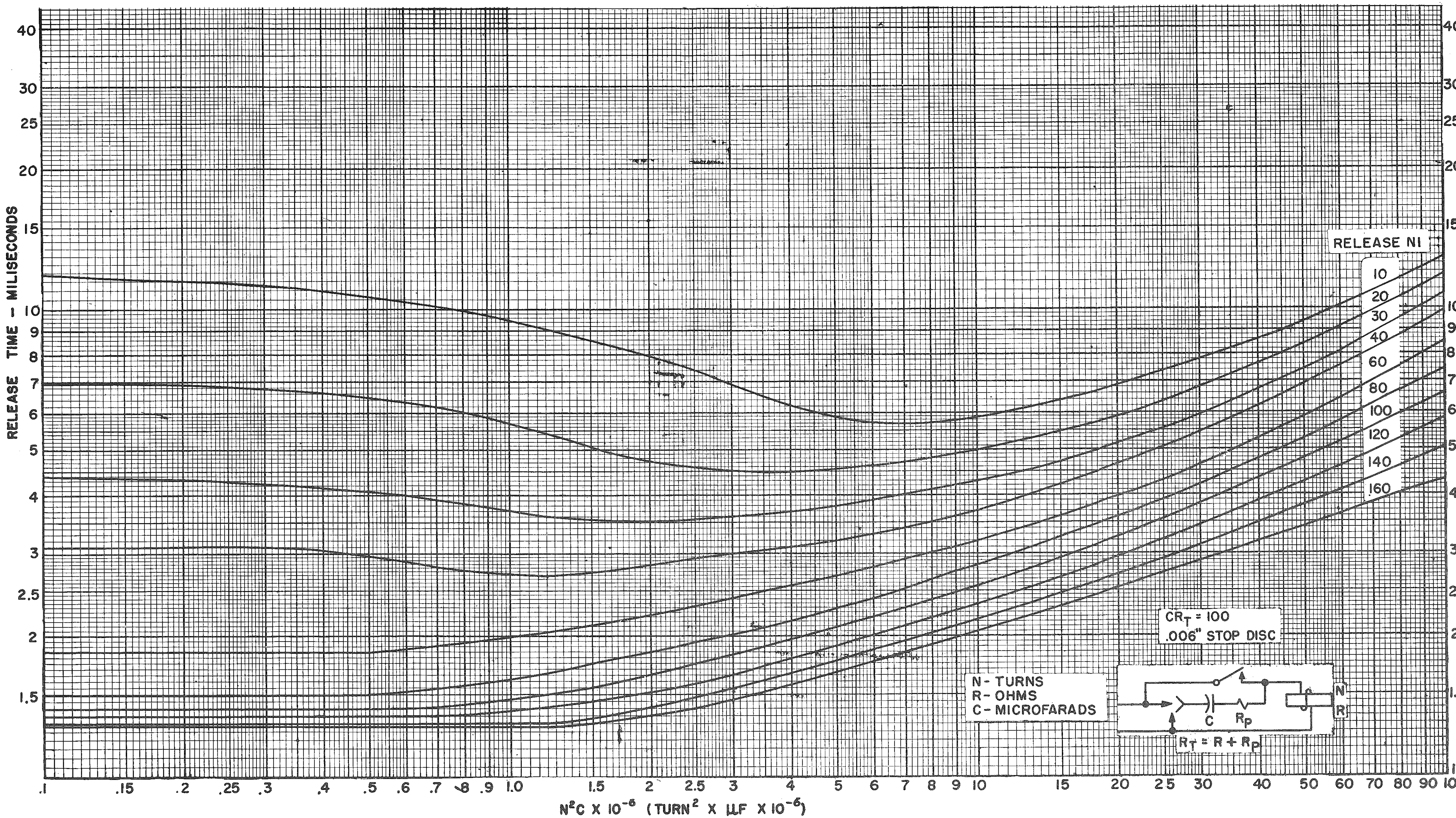


Fig. VII-15 - AF Relay - Maximum Release Time
With Contact Protection



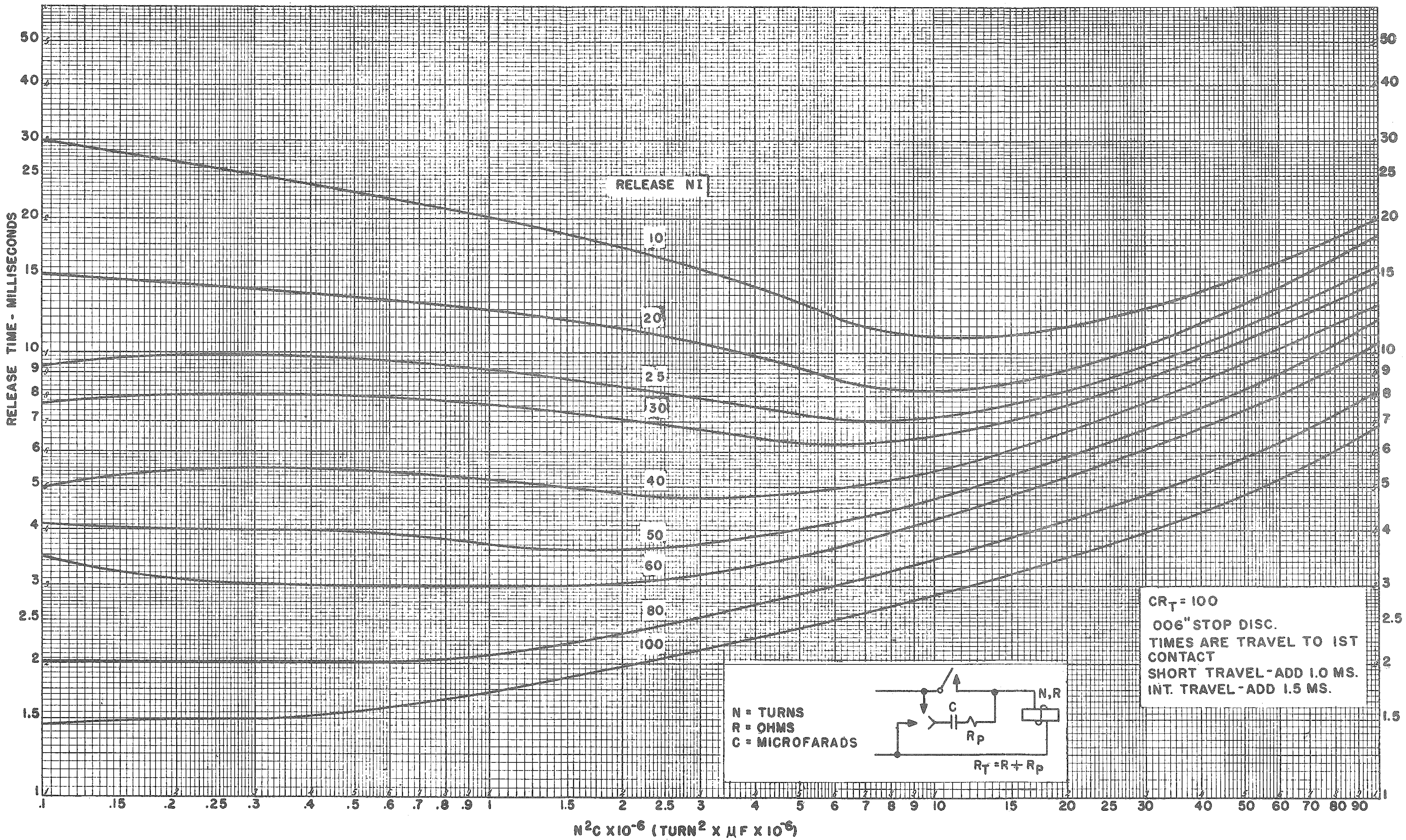
X-75509

Fig. VII-16 - AF Relay - Correction for Different Contact Protections



X-75509

Fig. VII-17 - AF Relay - Minimum Release Time
With Contact Protection



X-75509

Fig. VII-18 - AJ Relay - Maximum Release Time With Contact Protection

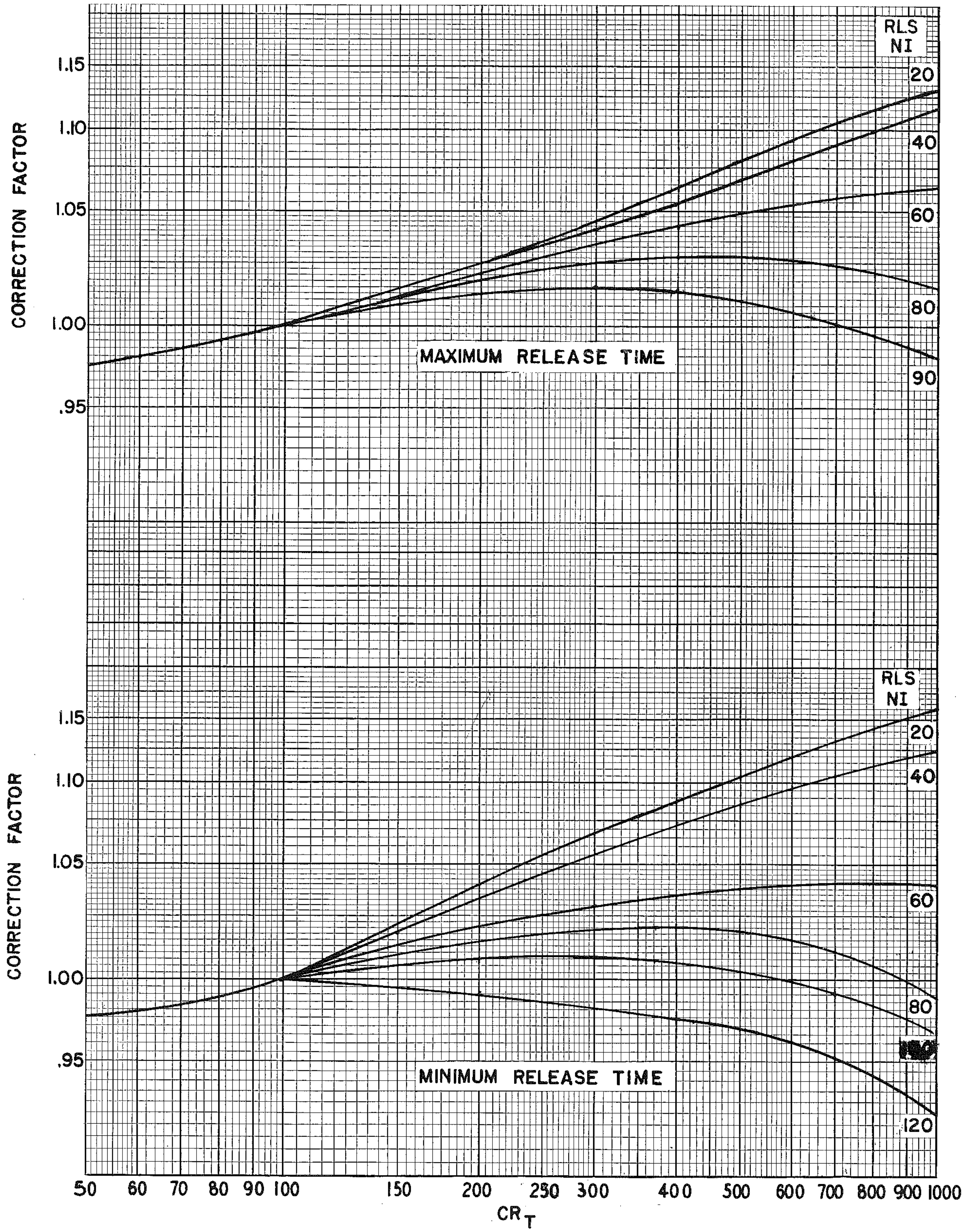


Fig. VII-19 - AJ Relay - Correction for Different Contact Protections