"EFFECT OF POWER SYSTEM TRANSIENT ON OPERATION TIME OF PROTECTIVE RELAYS"

A
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CERTIFICATE

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ABSTRACT : The effect of transients on the operating time of fast relays is important in determining the effectiveness of the power system protective devices. The operating time is a function of the circuit parameters including the instrumentation, the gap spacing as well as switching transients.

Analytical expressions of transient current have been developed. The effects of transients on the operating time of overcurrent relay are determined experimentally. Operating times for both transient and steady states condition have been found. Experimental observations establish that operating time of the relay is reduced by a wide margin 3.6% to 20.8% due to transients from the steady state value for the overcurrent relay of GEC make type. Switching transients for the relay circuits are 187.5% to 128.1% of the normal steady state value.

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CHAPTER - I

1.1 INTRODUCTION

The extensive use of electric energy in the diverse branches of the natural economics has made the reliability of operation of electrical equipment in power generating and distributing systems and in electric power consumer installations a problem of special importance.

Ever present in the every day operation of electric power system is the possibility of disturbances in normal operation and the appearance of faults in the separate parts of their equipment.

The most common form of disturbance in normal operation of electrical equipment is overloading, due to which the flow of current exceeds rated value.

The most severe and common form of faults are the short circuits. The magnitude of a short-circuit current depends on the kind and character of the short circuit, the power capacity and circuit arrangements of the system, the method of connection and operation of the transformer neutrals, the distance of the fault from the generating units, the ratings of the main equipment and the current limiting devices, the duration of the short circuit, the speed of action of the regulating and switching apparatus in the system and other factors.

As a rule, the short circuit current considerably exceeds the rated current of the affected installation and can materially disturb the normal operation of an electric power system. In fact, the short circuit cannot only lead to damage of equipment or the circuit element in which it develops, but also cause a considerable drop in voltage and frequency at which stable parallel operation of the power units is hampered. Short circuit may, further more, cause meters to draw large currents, lead to switch off of a series of power consumers, increase the energy ~~kaxxxax~~ losses in all parts of the power system etc.

The characteristic high degree of interconnection and interdependence existing between the various elements of an electric system and its conditions of operation creates a need for the use of protective devices and arrangements that will automatically and very quickly disconnect the faulty section from the system, or initiate an alarm of disturbances in normal operating conditions. In electric power systems these functions are performed by system of protective relays, each constituting a relay protection scheme. Historically, protective relays were one of the first forms of automatic control in power engineering and at the present time are one of the basic forms of automatic control employed in electric system.

The term protection relaying applies to the arrangement of devices set up in schemes capable of response to the appearance of a fault or a disturbance in normal operating conditions in any section of the electric system and of automatically acting on disconnecting apparatus or an alarm device.

Depending on the form and parameters of the circuit element to be protected as well as its functions in the system, the protective relay scheme will have to satisfy various requirements.

It is the latter that determine what operating principle and protective relay scheme should be selected. As a rule on the occurance of short circuit which may lead to heavy disturbance in normal system operation (damage to equipment, impermissible drop in voltage etc.), the protective relay scheme is designed to disconnect the damaged system element.

The protective scheme is designed to energise an alarm or signal whenever the overloads and short circuits do not present a direct danager to the faulted circuit element and the entire installation for example, an occurance of a single phase fault to earth in overhead circuits operated with an insulated newtral. In such cases it is possible for the operating personnel to take the necessary measures for removal of the abnormality and prevent any interruption in power supply to consumers.

The protective relay. scheme can consist of one or several relays designed to operate not only instant taneously, but also with time delay, can employ relays of diverse type and construction etc.

1.2 <u>Cause of Faults</u>: Insulation is usually either air or high resistivity material which may also be used as a mechanical support. Air insulation can accidentally be short circuited by birds, redents, snakes, kite strings, tree limbs etc. or reduced in insulation strength by ionisation due to lightning or a fire. Organic insulation can deteriorate due to heat or ageing or can be broken down by over voltage due to lightning, switchings surges etc. Porecalain insulators can be bridged by moisture with dirt or salt and can become cracked. In all these cases the initial lowering of insulation resistance causes a small current to be diverted which hastens deterioration or ionisation, causing this current further to increase in a progressive manner until a power fault occurs. Further more, heavy faults, if not quickly interrupted may heat conductors sufficiently to cause deterioration of other insulation which was previously in a healthy state.

(Line and apparatus insulation may be subjected to transient over-voltages whenever current is started or stopped. These surges are a component of the recovery voltages. The most severe switching surges occur when current which lags or leads the applied voltage by 90° degrees is (such as short circuit current or line charging current) interrupted. During unloaded line dropping on a grounded system, the line voltage may go to erest line to neutral voltage on the first interruption; three times this value on the first restrike; five times this value on the econd restrike; and so on as the are restrikes on succeeding half cycles. The magnitude of these switching surges is appreciably greater for systems that are not solidly grounded. Thus system insulation may be subjected to serious over-voltages with breaker recovery voltages that are still higher when line charging current is interrupted.

1.3 Economics of Relaying:

The cost of protective relays is generally small(½ to 2%) compared with the cost of the equipment protected. This is particularly true in the case of generators, transformers, and high tension lines. Inspite of this there is a tendency to treat protection not as a small percentage insurance charge but as a separate item and then to price the cheapest relay or relay scheme. Considering the saving in repair cost afforded by high grade, high speed relaying compared with cheaper slow-speed arrangements, it astonises many engineers that the best protection is not always chosen the cost of one major repair to a generator for instance would be many times the cost of the best protective relay schemes.

Similarly, the cost of one day's loss of production in a copper mine or oil refinery may exceed the cost of adequate relaying. On the other hand un-necessarily expensive and complex protection scheme are sometimes used for important lines so that the likelihood of an outage due to trouble in the protection gear may be comparable with the likelihood of an actual fault.

It is the duty of the protection Engineer to choose the most economical scheme which will give complete protection and isolate faults selectively in the shortest ppossible time. Good electrical service i.e. continuity of supply, depends to a great extent on adequate protection. This is sometimes difficult to achieve because of the tendency of system planners to relegate the relaying considerations until the system arrangement has been decided on and the equipment ordered; this often creates conditions that make it almost impossible to find anything on which the relay can base its selective measurement. In short, protection must be considered before the power system layout is finalised.

1.4 PROTECTION SCHEME EQUIREMENTS:

Fundamental requirements which protective relay schemes must meet are the following:

1. Quickness of action: Quick disconnection on occurence of a short circuit decreases the amount of damage incurred, helps maintaining the stability of machines operating in parallel, betters conditions for pulling meters into synchoronisation and allows them to self-start, onsures maintenance of normal operating conditions in the unfaulted sections of the system, decreases total outage of power consumers and total non-delivery of electric power.

The time interval within which a faulted circuit section is disconnected from power is a sum consisting of the operating times of the protection schemes (t_p), and of the circuit breaker together with its operating mechanism (t_{cb}), namely;

$$t_{oper} = t_p + t_{cb}$$

To raise the reliability of power system operation, as a rule, the more quick acting protection schemes should be employed in conjuction with quick acting circuit breakers.

Protection schemes incorporating time delay are used whenever protective action must be co-ordinated between adjacent circuit zones and whenever system operating conditions permit time delay in the event of a short circuit.

On the other hand, application of quick acting circuit breakers sometimes prove to be impracticable. For instance, if on an overhead transmission line equipped with tubular-type lightning arrestors the latter operate, quick-acting protection scheme may disconnect the line. No intentional increase in protection operating times is necessary whenever the line is equipped with ground wires and automatic reclosing controls. The presence of the ground wires limits the probability of surge faulting with subsequent lightning arrestor operation, and any possible improper switch out of the line will be erected by the automatic reclosing controls.

Another example of where quick acting protection cannot be used is when the protection schemes of adjacent circuit sections must be co-ordinated for selective operation.

2. Selectivity or discriminating action:

The ability of the protection to 'select' (search out) the point at which the fault appears and switch it out of the circuit by tripping the nearest of the circuit breakers. Protection scheme selectivity is accomplished by accordingly co-ordinating the pick up (operating) current or time setting in the corresponding protections at the consecutively connected circuit sections. This involves having the largest pick-up (operating) current or time settings in the protections of the circuit zones located closest to power supply. In order to quickly and with selectivity clear a fault on sections near the source of power supply, it becomes necessary to employ the protections to be studied further below, the over current cut-offs, or more complicated types of protection, such as for example the distance protections.

It may also be come necessary to resort to non-switching corrected by automatic reclosing controls or automatic stand by connection controls.

3. <u>Sensitivity:</u> The capability of the protection to respond to abnormalities in normal operating conditions, and to the short circuit for which the protection has been designed. It is accepted that the sensitivity of a protection can be expressed by a sensitivity factor K_s . The sensitivity of a protection is easy to understand by reference to overcurrent and under voltage protections.

For overcurrent protections where response takes place on an increase in current.

$$K_s = \frac{I_{sc} \min}{I_{pp}}$$

where I_{sc} min - The calculated minimum short circuit current of a solid metallic short circuit (i.e. transition resistance at fault taken equal to zero) at far end of protected circuit section I_{pp} - Primary pick up (or operating) current of the proection.

For undervoltage protections where the protection operates on drop in drop during short circuit:

$$K_s = \frac{V_{p\theta}}{V_r} \max.$$

where $V_{p\theta}$ = Voltage at which protection operates

V_r max - Calculated Max[m] residential voltage at point where protection is installed when short circuit secures at far end of protected circuit section.

It is usually required that the sensitivity factor should not be less the 1.5 to 2.0 in value.

4. <u>Reliability:</u> Reliability in operation on occurance of all the faults for which the protection has been designed. In examining questions of protection scheme reliability it is necessary to take into consideration the difficult conditions and specific operating requirements which must be met by protective relay schemes and consisting in that the protective relay scheme must continuously be on the alert over long interval of times (month and years) and operate reliably. The moment the occasion arises the simpler the protection scheme and less the number of relays, circuits and contacts it contains, the greater is relaibility. Simplicity of construction and adequate quality of the relays, correctness of design and installation, as well as qualified maintenance and supervision are also facts which influence protection scheme reliability. Protection scheme reliability, as generally accepted, is evaluated on the basis of percentage of correct operations has reached a value of 98 to 99 % in power system.

In selecting a type of protective scheme it is necessary to strive to make it as simple and reliable as possible. Faults and conditions of operation practically improbable of occurence should not be taken into consideration.

Proective relay schemes serving to energise a signalling circuit, with the exception of quick action, must meet requirements similar to those faced by schemes serving to energise a trip circuit. But in view of the fact that signal energising protection schemes bear less responsibility their requirements are less stringest and are usually not prescribed in standardised regulations are rules.

1.5 DEFINITIONS OF IMPORTANT TERMS:

1. Stability: The quality in a power system which enables it to maintain a state of equilibrium and regain it after disturbance.
2. Sensitivity : It is the quality of the device to pick-up the smallest value of detected impulse for its operation.
3. Selectivity: It is the quality of the device to assess if the detected impulse requires its co-operation for minimum outage on the system.
4. Co-ordination: Setting of one relay with reference to another to give disconnection and provide sensitive and selective operations.

5. System : Transmission and or distribution network of lines, transformers and generators.

6. Voltage surge : It is a sudden deviation of voltage from normal conditions and may be caused by lightning, switching operation and/or faults.

7. Reserve capacity: It is the generating capacity available in reserve which can be brought on bar as and when required.

8. Auto-reclosing: The ability incorporated in a circuit breaker to reclose itself it has tripped under fault without the system falling apart.

9. Automatic-voltage regulators:

   Auxiliary equipment which regulates voltage within limit by itself, without external manipulation.

10. Operating time: The time which elapsed from the moment when the attracting quantity attains a value equal to the pick up value until the relay operates its contacts.

11. Reach: The remote limit of the zone of protection provided by the relay; used mostly in connection with distance relays to indicate how far along a line the tripping zone of the relay extends.

12. Over-reach:
Under reach   Errors in relay measurement resulting in wrong operation or failure to operate respectively.

13. Blocking: Preventing the protective relay from tripping, either due to its own characteristic or to an additional relay.

14. Tapped Line: One which has one or more tapped lines connected to it for supplying loads.

15. Multi-terminal Lines: One with three or more terminals which can be power sources.

16. Flag or Target: A visual device, usually spring or gravity operated, for indicating the operation of the relay.

17. Instantaneous relay: One which has no intentional time delay and operates in less than 0.1 second.

18. Time delay relay unit: One which is designed with a delaying unit. A self contained relay unit which, in conjuction with one or more other relay units in a relay case, constitute a complete protective relay.

19. Element: A part of a relay unit, such as an electromagnet or damping magnet or an inductive disc.

20. Burden
(Power Consumption) : The power absorbed by the circuits of the relay, expressed in volt-amperes if alternative current (a.c.) and in watts if direct current (d.c.) at the rated current or voltage.

21. Consistency: The accuracy with which the relay can repeat its electrical or time characteristics.

22. Power Switching: An oscillation between groups of synchronous a.c. machines caused by an abrupt change in load conditions.

23. Back-up relay: A relay which operates, usually after a slight delay, if the normal relay does not operate to trip its circuit breaker.

24. Primary Relays: These which are connected to the protected cirduit through current transformers (C & t's) and potential transformers (P.t's).

25. Seal-in-relay: Similar to reinforcing relay except connected to stay until its coil circuit is interrupted by a switch on the circuit breaker.

26. Dropout or reset (level): The value of current or voltage, which is the threshold below which the relay will open its contacts and return to normal position or state.

27. Pick-up (Level): The value of current or voltage etc. which is the threshold below which the relay will open its contacts and return to normal position or state.

28. Operating force or torque: That which tends to close the contacts of the relay.

29. <u>Restraining Force or Torque</u>: That which opposes the operating force or torques and tends to prevent the closure of the relay contacts.

30. <u>Trip coil</u>: It is a coil which when energised acuates a plunger which in turn actuates the tripping mechanism of the switch gear.

1.6 CLASSIFICATION OF RELAYS:

Relays may be classed as electrical, mechanical, optical, accoustical and other forms of relays. Here we are concerned only with electrical relays.

Electrical relays in turn may be sub-divided in the following ways.

(a) As to the principle of action on the relay system: Electro-magnetic, moving coil, induction, electro-dynamic, polarised, electronic, thermal relays.

(b) As to the nature of quantity to which the relay responds. Current, voltage, power reactance, impedance, frequency, phase-shift relays.

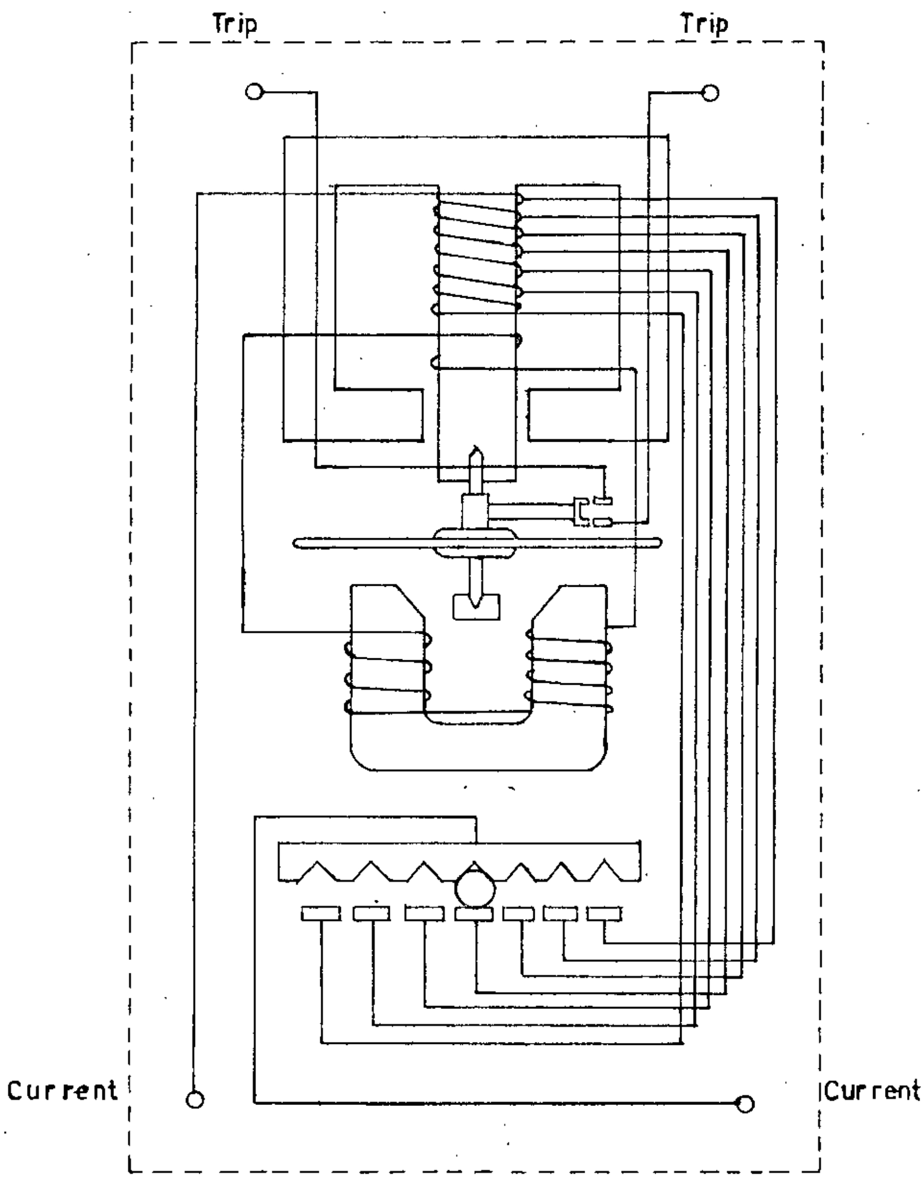
(c) As to the method of sensing element connection (i) primary relays (ii) Secondary relays.

(d) As to the method by which the control element acts upon the disconnecting device. (i) Direct acting relays (ii) Indirect acting relays.

(e) As to the degree of importance (i) Main (ii) Supplementary.

(f) As to the time of action (i) Relays without time delay (ii) Relays with time delay.

((g) As to the kind of contact (i) Normally open (n.o.) (ii) Normally closed (n.c.).

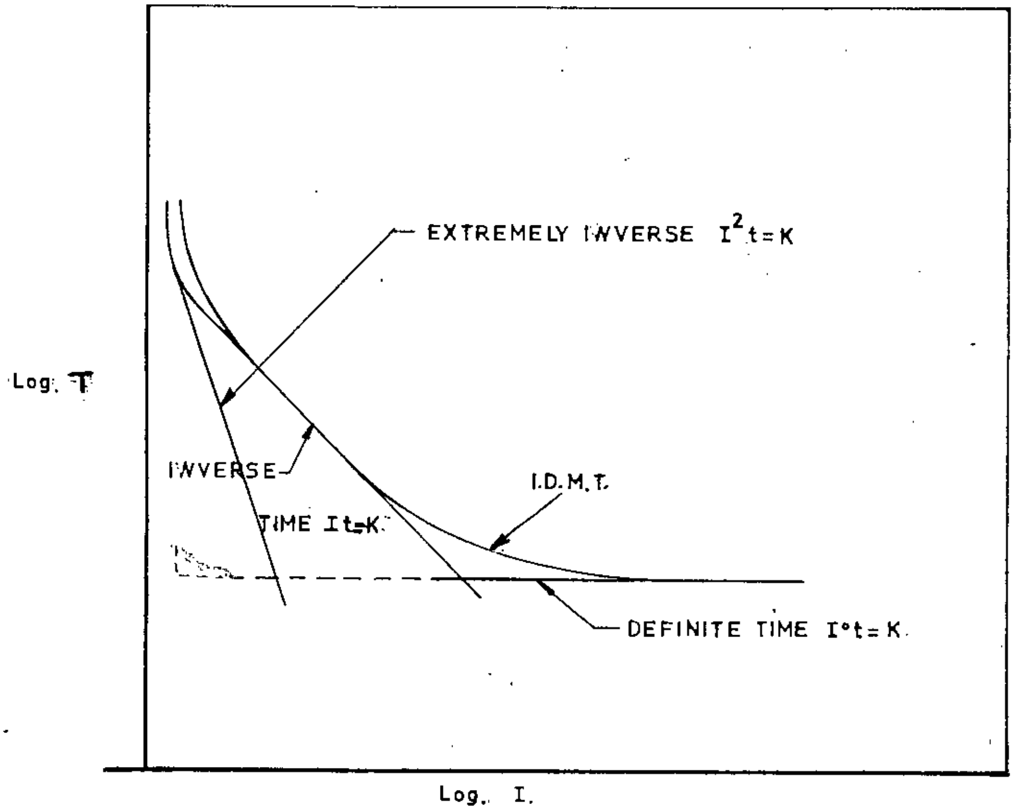


INDUCTION-TYPE
OVER CURRENT RELAY
FIG. 1.

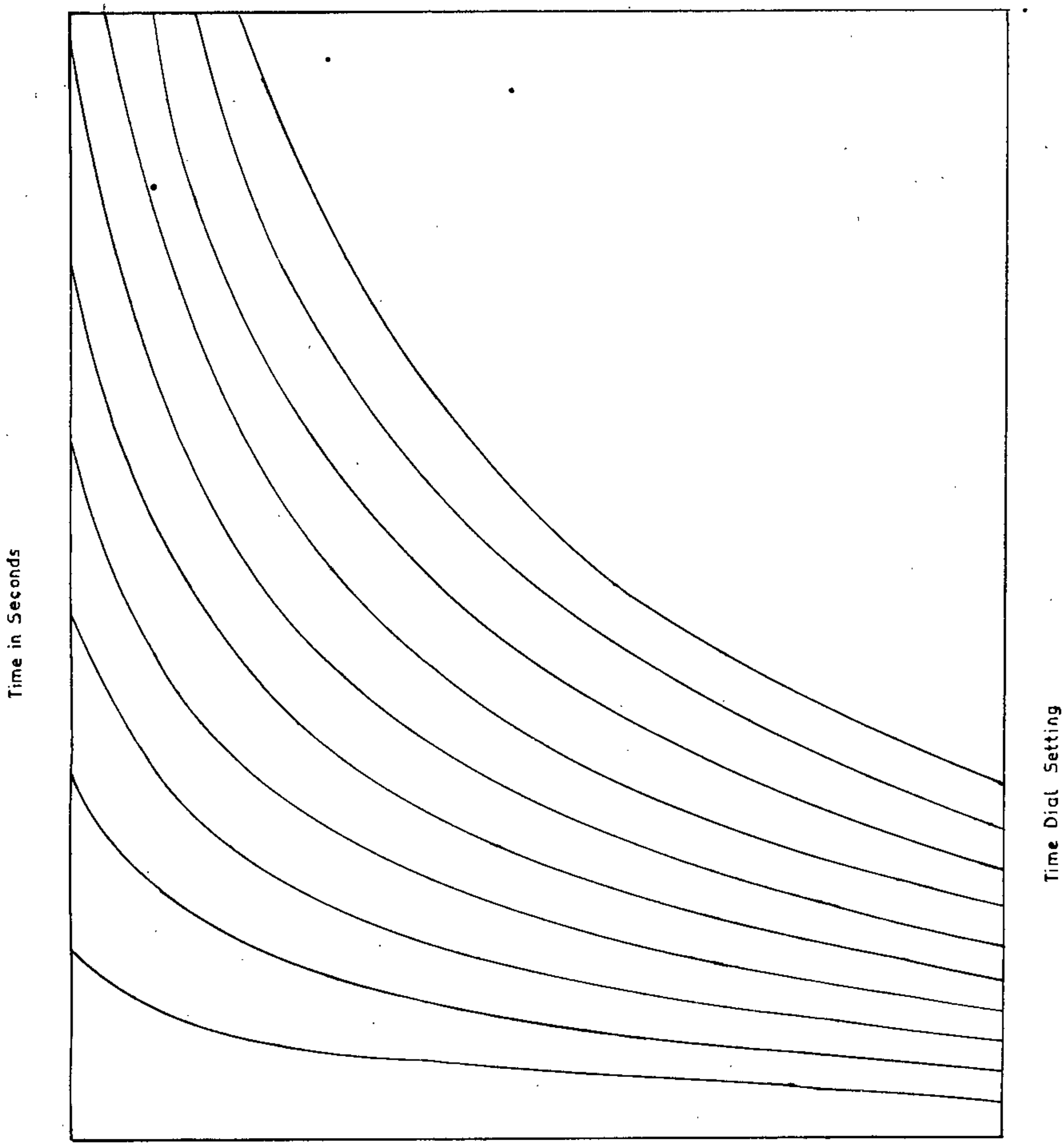
1.7 OPERATION OF AN OVER CURRENT RELAY:

An over current relay consist of two magnets as shown in the fig. 4 It is essentially similar in construction to an induction type of meter. The upper electromagnet consists of two winding. One is supplied from a current transformer in the line which is to be protected. This winding has got tappings at an interval and are connected to a plug-setting, thereby giving the desired current setting. This winding energises a second coil on the magnet by induction the current from the second winding passing through coil in the lower electromagnet. In this way, the leakage flux from the upper and the flux produced by the lower are displaced in phase to set up a rotational torque on the metal disc suspended between the two magnets. The disc spindle carries a moving contact which bridge two fixed contacts where the disc has rotated through an angle which can be adjusted. Any desired time setting can be given to the relay by adjusting the angle. The definito minimum time characteristics is obtained by allowing the iron in the upper electro magnet to saturate so that there is practically no increase in flux after the current has reached a certain value.

TIME CURRENT CHARACTARISTICS



INVERSE, DEFINITE &
I.D.M.T. CHARACTERISTIC OF RELAYS :
FIG. 2.



Multiples of Minimum Closing Current

Fig. 3A.

1.8 TIME CURRENT CHARACTERISTICS

A General expression for the operating time of a time current relay is

$$t = \frac{KM}{I^n - I_p^n} \qquad (1)$$

where I is the multiple of tap current, I_p is the multiple of tap current at which pick-up occurs. K a design constant of the relay and M is the time multiplier setting. If the relay picks at tap value of current, then equ (1) becomes $t = \frac{KM}{I^n - 1}$ Depending on two design factor, linearity of B - H curve of the magnet desired slope of the value of K and M and n vary. For standard IDMT relay $n < 1$ and for very inverse $n = 1$ and for extremely inverse characteristic n is greater than one. Different countries use diffierent value of n and K for IDMT overcurrent relay.

For our ~~pxxxx~~ purposes the curve will be asymptotic in nature. The time setting only shifts the curve as shown in the Fig. 3A.

1.9 REVIEW OF LITERATURES:.

About a century age, a power system usually consisted of a small generator supplying power. The station attendant in an emergency used to open switches manually. The size of power system began to double and quadruple per decade. Industrial revolution in different countries brought about a drastic change in the power system. They began to use integrated Power Systems among themselves. Engineers, Planners and designers began to use more and more automatic switch gear with the increase in the size of power plant and its transmission. Such apparatus must operate in a small fraction of a second of the system is to avoid destruction.

Fuses were used as a first stop of automatic devices to isolate the faulted equipment quickly. These were used widely and mainly for distribution circuits. The great disadvantage was that these needed replacement before the supply could be restored. These inconveniences were overcome by the use of automatic circuit breaker with a trip device. Finally protective relays came into picture which began to control the trip coil of the breaker.

Initially the relays were designed to operate in responses to short circuit conditions of the system. These relays were attracted armature type with or without a definite time delay provided by a dash pot mechanism. The greater size of the system demanded more precise relay mechanism. The only device was the wait hour meter which was turned into a relay by substituting contacts for the indicating register. This resulted in the inverse time overcurrent relay which is still in use although in an improved and modified form.

The induction disc inverse relay was introduced in early 1920's and high speed differential type in late 1920's. Greater sensitivity and accuracy have been achieved particularly since 1939-45 War by the use of polarised d.c. relays energised through rectifier bridges.

During 1920 to 1940 -50 a large number of research work have been done on construction and type of relays.

Repaid development of complicated and integrated power system and increasing use of automation compelled engineers design more rapid and sensitive type of relays.

(Transients before this were of no importance because it did not affected the operating time of the relays. This was because transients [illegible] died down before the operation of the relays. Relays which operate in fraction of seconds are affected most with the switching transients. Although some works on transients of power system have been done sine 1950 till today; but their scope were limited. Some of the works are being mentioned below.

"Transient characteristics of Current Transformers during faults"by C. Concordia, C.N. Weygandt and H.S.Scott. (1) This work dealt mainly with the dynamic characteristic of current transformers during fault in the power system. The paper did not touch at all on the effect of transient on replay operating time.

"Current Transformers and Relays for High Speed Differential Protection with particular reference to offset transient currents" by W.K.Sonnemann and C. Wentz (2) also dealt with transients characteristics of current transformers in a power system with relays for High Speed Differential Protection. Some deerivatives were made of the circuit parameters. The paper did not deal with the change in operating time of relay due to transient.

"Transient Characteristics of Electromagnetic Relays" by Charles Cameron and D.D. Lingelbach (3) has considerably dealt with the dynamic characteristic of a d.c. operate electromagnetic relays. Effects of non-linerity in the B - H curve have been taken into consideration. The presence of the discharge resistance in the circuit accidentaå or planned has been considered and it has been shown that it increases the release time of relay. This paper also did not touch on the effect of transient on the operating time of a relay. Further more relays operated by A.C.Supply has not been considered at all.

" Transient in distance protection" by P.Mathews and B.D.N. (4).

Analysis of the behaviour of distance relays in transient conditions from stand point of reducing relaying times. ~~Although~~ Alternate means of elimination or equating transient secondary current and voltage signals, use of secondary replica impedances, effect of relaxation transient in voltage transformer secondary circuits are considered.

" An analysis of transient phenomonon in electro-magnets" by V.A.Karasev [5]

All purpose families of curves have been plotted by means of computer so that magnet operatint time and synamic characteristics can be found. This paper has overlooked the effect of power system transient on the operating time of a relay.

" Approach to the analysis of the dynamic phenomena occuring at contact make in a supply built flaxure operated relay spring assembly with springs of a geometric form" by Goran Wikell [6] deals with mathematical analysis of force on simply built operated relay spring during "Chatter". Dynamic phenomena occuring at contact make has been fully considered.

" Ultra-Rapid Static Relay for Distance Protection" -by M.Soullard [7] gives a detailed study of relays for measuring transient state values of inductance and resistance.

The papers deals with the technique of transient state values of inductance and resistance.

"Control Circuit Transient by W.C.Kotheimer [8] deals with the causes of surges and how the design engineer can deal with them in ERV power circuits and control circuits.

"The requirements made of Current Transformers by High Speed Protective Relays" - by N.Korpany and H.Ungrad [9].

Performance of current transformers is discussed including transient and overcurrent characteristics selection of current transformers based on the requirements of static relays have been considered.

"Suppressession Protects Solid State Equipment by "W.C.Robert [10] Battery transient suppressor protects solid state equipment against damage or misoperation due to transient high voltages.

"Transient Voltages in Relay Control Circuits" by W.R.Sonnemann [11].

Typical cases to serve as guide for trouble shooting when transient overvoltage occassioned by circuit interruption is experienced in control circuits. Informations on measurement technique is also included.

From the available literatures and reference on relays in Bangladesh it is quite apparent that no work seems to have been done on systematic determination of the effect of transient on relay operating time. Our work therefore is the first of its kind is Bangladesh. An humble attempt has been made for experimentally determing the effects of switching transient in a system on the operating time of an overcurrent relay. The relay used in experimentation was of GEC make type. Lack of suitable facilities have compelled us to give the results of only one relay.

CHAPTER -II

2. MATHEMATICAL ANALYSIS.

2.1 Linear Tratement

Let us suppose that the resistance and inductance of a power system is lumped in a single series resistance R and inductance L. The series inductance L includes the inductance of the relay coil. The expression for dynamic equilibrium will therefore be

$$E_m \operatorname{Sin} (wt + \lambda) = L \frac{di}{dt} + R_i \qquad (1)$$

The inductance is the above equation is being considered contant. The symbol λ denotes the phase of the voltage wave at which the switch of the fig. 3B is closed.

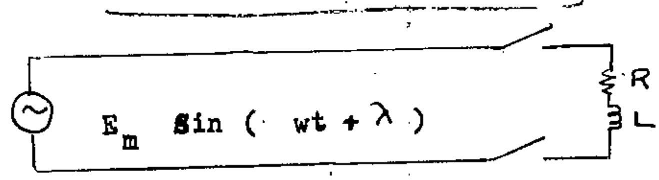


Fig 3B

The phase angle λ , as will be shown in the solution of the differential equation, determines the magnitude of the ac transient and prevides a convenient means of examining a - c transient conditions.

The time of cyle at which the switching operation is performed, determines in general the magnitude of an a - c transient. Most switching operations are performed with no regard for, or rather no knowledge of, the point on the voltage wave at which the transient period begins.

The equitions (1) is a simple differential equation of the order one. Hence its solution consists of a complementary function and a particular integral.

The complementary function is given by

$$L\ di/dt + Ri = 0 \quad \text{i.e.} \quad \frac{di}{dt} = -\frac{Ri}{L}$$

$$\text{i.e.} \quad \frac{di}{i} = \frac{R}{L}\,dt$$

$$\text{i.e.} \quad Ln(i) = \frac{-R}{L}t \quad C_1$$

$$\text{i.e.} \quad i = A\,e^{\frac{-R}{L}t} \qquad (2)$$

<u>Particular integral:</u>

Since we are dealing here steady state case it is expected that the final current in the circuit could vary according to sinusoidal function of the time with the same frequency as the impressed e.m.f. But the current and e.m.f. may not ~~in~~ alter in the same phase.

Let the solution be of the form.

$$i = B \sin(wt + \lambda - \theta) \qquad (3)$$

where B is the amplitude and θ is the phase constant to be determined.

If equation (3) is the solution of the differential equation then it must satisfy the eqn.(1).

From equation (3) we have

$$\frac{di}{dt} = Bw \cos(wt + \lambda - \theta) \qquad (4)$$

Equation (1), (3) and (4) yield.

$$LBw \cos(wt + \lambda - \theta) + Ri = E_m \sin(wt + \lambda)$$

$$\text{i.e. } LBw \cos(wt + \lambda - \theta) + RB \sin(wt + \lambda - \theta) = E_m \sin(wt + \lambda)$$

$$\text{or } LBw \left\{ \cos(wt + \lambda) \cos\theta + \sin(wt + \lambda) \sin\theta \right\} + RB \left\{ \sin(wt + \lambda) \cos\theta - \cos(wt + \lambda) \sin\theta \right\} = E \sin(wt + \lambda)$$

$$\text{or } \cos(wt + \lambda) \left\{ LBw (\cos\theta - RB \sin\theta \right\} + \sin(wt + \lambda) \left\{ RB \cos\theta - E_m + LBw \sin\theta \right\} = 0 \qquad (5)$$

Eqn. (5) is satisfied for all values of t if the expressions under brackets are individually zero. Thus we must have

$$w\,LB\cos\theta - RB\sin\theta = 0$$

and $$RB\cos\theta - E_m + LBw\sin\theta = 0$$

$$\text{i.e. } wL\cos\theta = R\sin\theta$$

$$\text{i.e. } \frac{wL}{R} = \frac{\sin\theta}{\cos\theta} = \tan\theta$$

$$\text{i.e. } \theta = \tan^{-1}\frac{wL}{R} \qquad \ldots\ldots \qquad (6)$$

$$RB\cos\theta + LBw\sin\theta = E_m$$

$$\text{Or } RB\frac{R}{\sqrt{w^2L^2 + R^2}} + LBw\frac{wL}{\sqrt{w^2L^2+R^2}} = E_m$$

$$\text{Or } B\left\{\frac{R^2}{\sqrt{R^2 + w^2L^2}} + \frac{w^2L^2}{\sqrt{R^2+w^2L^2}}\right\} = E_m$$

$$\text{Or } B\left\{\frac{R^2}{\sqrt{R^2 + w^2L^2}} + \frac{w^2L^2}{\sqrt{R^2+w^2L^2}}\right\} = E_m$$

$$\text{Or } B\left\{\frac{R^2}{R^2 + w^2L^2} + \frac{w^2L^2}{R^2+w^2L^2}\right\} = \frac{E_m}{\sqrt{R^2+w^2L^2}}$$

$$\text{Or } B\left(\frac{R^2 + w^2L^2}{R^2 + w^2L^2}\right) = \frac{E_m}{\sqrt{R^2+w^2L^2}}$$

$$\text{Or } B = \frac{E_m}{\sqrt{R^2+w^2L^2}} \qquad \ldots\ldots \qquad (7)$$

$$\therefore \text{ from eqn. (3) } i = \frac{E_m}{\sqrt{R^2 + w^2 L^2}} \sin (wt + \lambda - \theta) \qquad (8)$$

$$\text{where } \theta = \tan^{-1} \frac{wL}{R}$$

which is the steady current under these conditions. The actual current is the sum of the currents given in eqn (2) and (8)

The value of A in eqn.(2) can easily be determined from initial value of current.

$$i = A e^{\left(\frac{-Rt}{L}\right)} + B' \sin (wt + \lambda - \theta)$$

$$i = A e^{\left(\frac{-Rt}{L}\right)} + \frac{E_m}{\sqrt{R^2 + w^2 L^2}} \sin \left(wt + \lambda - \tan^{-1} \frac{wL}{R}\right) \qquad (9)$$

At $t = 0$, the current is zero. This gives us from the above eqn. (9).

$$0 = A + \frac{E_m}{\sqrt{R^2 + w^2 L^2}} \sin \left(\lambda - \tan^{-1} \frac{wL}{R}\right)$$

$$\text{i.e. } A = -\frac{E_m}{\sqrt{R^2 + w^2 L^2}} \sin \left(\lambda - \tan^{-1} \frac{wL}{R}\right)$$

$$\therefore i = \frac{E_m}{\sqrt{R^2 + w^2 L^2}} \sin \left(wt + \lambda - \tan^{-1} \frac{wL}{R}\right)$$

$$- \frac{E_m}{\sqrt{R^2 + w^2 L^2}} \sin \left(\lambda - \tan^{-1} \frac{wL}{R}\right) e^{\frac{-Rt}{L}}$$

$$\therefore i = \frac{E_m}{\sqrt{R^2 + w^2L^2}} \operatorname{Sin}(wt + \lambda - \theta) - \frac{E_m}{\sqrt{R^2 + w^2 L^2}} \operatorname{Sin}(\lambda - \tan^{-1}\frac{wL}{R}) e^{\frac{-Rt}{L}}$$

$$\text{where } \theta = \tan^{-1}\frac{wL}{R} \qquad (10)$$

The second term ~~represent~~ represents the transient current which decays expenentially. It has an initial value equal and opposite to that of the a.c. component at the time of switching (so that the initial current is more).

If the circuit is very inductive $wL \gg R$

and we may put $\sqrt{R^2 + R^2 L^2} \simeq wL$

and $\tan^{-1} \frac{wL}{R} = \frac{\pi}{2}$

The current then becomes

$$I = \frac{E}{wL} \operatorname{Sin}(wt + \lambda - \frac{\pi}{2}) - e^{\frac{-Rt}{L}} \operatorname{Sin}(\lambda - \frac{\pi}{2})$$

The current then becomes.

$$i = \left(\frac{E}{w L}\right)\left\{\operatorname{Sin}(wt + \lambda - \frac{\pi}{2}) - e^{\frac{-Rt}{L}} \operatorname{Sin}(\lambda - \frac{\pi}{2})\right\}$$

$$= \frac{E}{wL}\left\{e^{\frac{-Rt}{L}} \operatorname{Cos}\lambda - \operatorname{Cos}(wt + \lambda)\right\}$$

During the early period after switching $e^{\frac{-Rt}{L}}$ does not decay rapidly from the value of unity, and the current is therefore approximately.

$$i = \left(\frac{E}{wL}\right)\left\{\mathrm{Cos}\,\lambda - \mathrm{Cos}\,(wt + \lambda)\right\} \qquad (11)$$

and varies between the value $\frac{E}{wL}(\mathrm{Cos}\,\lambda - 1)$

and $\frac{E}{wL}(\mathrm{Cos} + 1)$. The peak is thus

$$\frac{E}{wL}(1 + |\mathrm{Cos}\,\lambda|)$$

i.e. $(1 + |\cos\lambda|)$ times the normal peak value.

The maximum peak is thus obtained when $\lambda = 0$ and is twice the normal peak. This condition occurs when the circuit is closed at zero voltage and the current is $i = \frac{E}{wL}(1 - \mathrm{Cos}\ wt)$...(12)

which varies between zero (at $t = 0$) and $\frac{2E}{wL}$ (at $t = \frac{\Pi}{W}$)

It can be shown that whatever the power factor of the circuit may be the maximum "doubling effect" is obtained when the circuit is closed at zero voltage.

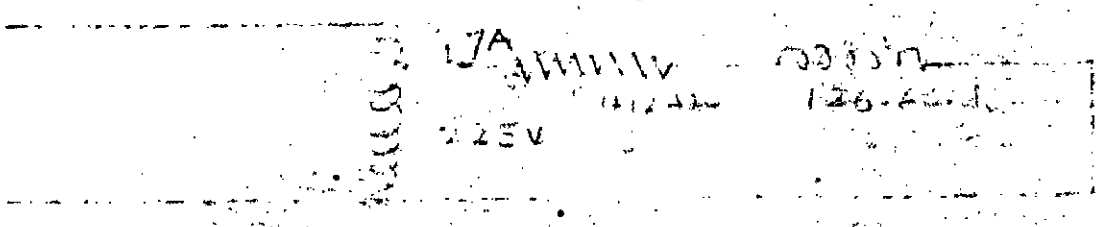


FIG. 4A.

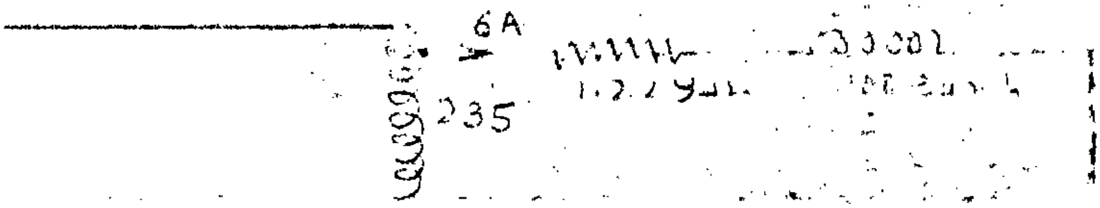


FIG 4B

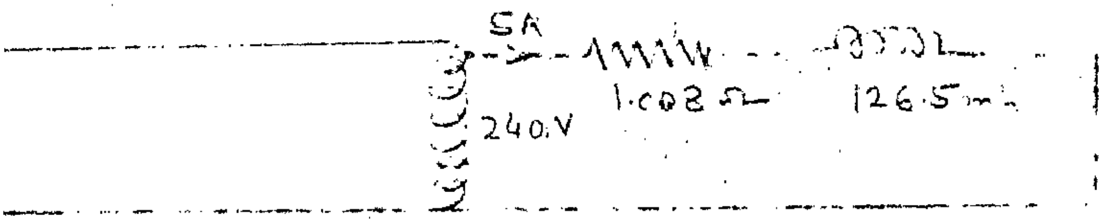


FIG 4C

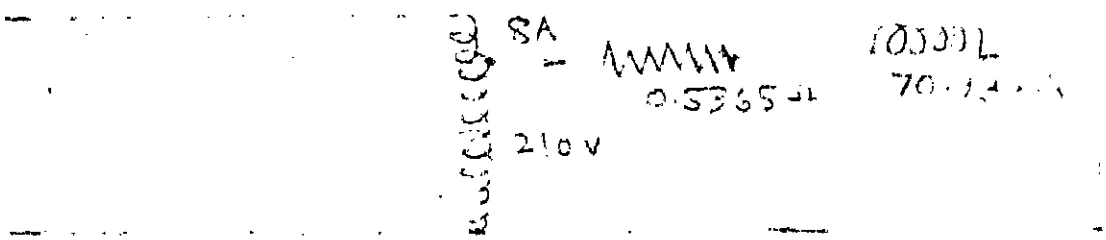


FIG 4D

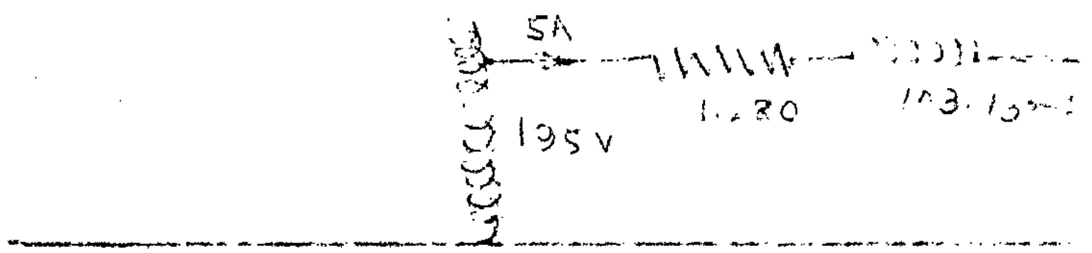


FIG 4E

2.2 Determination of time constants.

A.

$$Z = \frac{V}{I} = \frac{225}{4.7} = 47.872$$

$$R = 1.412 + 0.490 = \underline{1.902}$$

Since $Z^2 = X^2 + R^2$

$$\therefore \quad X^2 = Z^2 - R^2 = (Z + R)(Z - R)$$

$$= (47.872 + 1.902)(47.872 - 1.902)$$

$$= (49.774)(45.970) = \underline{2278.11478}$$

$$\therefore \quad X = \sqrt{2278.11478} = 47.73$$

$$L = \frac{47.73}{377} = 126.6 \text{ m henry}$$

$$\therefore \quad \text{Time constant} = \frac{L}{R} = \frac{0.1266}{1.902} = 0.06659 \text{ sec}$$

B.

$$Z = \frac{V}{I} = \frac{235}{6} = 39.166$$

Since $X^2 = (Z^2 - R^2) = (Z + R)(Z - R)$

$$= (39.166 + 1.719)(39.166 - 1.719)$$

$$= (40.885)(37.447) = 1518.755$$

$$X_L^2 = 1518.755$$

$$X_L = 38.97$$

$$L = \frac{38.97}{377} = 100.34 \text{ mh}$$

$$\therefore \text{ Time constant } = \frac{100.37}{1.719} \times 10^{-3} = \frac{0.10037}{1.719}$$

$$= 0.0585 \text{ secs}$$

C. Since $Z = X_L^2 + R^2$

$$X_L^2 = Z^2 - R^2 (Z + R)(Z - R)$$

Here $Z = \frac{240}{5} = 48$

$$X_L^2 = (48 + 1.498)(48 - 1.498)$$

$$= (49.498)(46.502)$$

$$X_L^2 = 2271.7560$$

$$X_L = 47.66$$

$$L = \frac{47.66}{377} = 126.5 \text{ mh}$$

$$\text{Time Constant} = \frac{1265.58}{1.498} \times 10^{-3} = 0.0845 \text{ secs.}$$

D.

Since $Z^2 = X_L^2 + R^2$

$\therefore \quad X_L^2 = Z^2 - R^2$

Heme $Z \frac{V}{I} = \frac{210}{8} = 26.25$

$\therefore \quad X_L^2 = Z^2 - R^2$

$= (Z + R)(Z - R)$

$= (26.250 + 1.0865)(26.250 - 1.0865)$

$= 27.3365)(26.1638)$

$= 715.218$

$X_L^2 = 715.218$

$X_L = 26.74$

$L = \frac{X}{2\pi f} = \frac{26.74}{377} = 70.93$ mh

Time constant $= \frac{70.93 \times 10^{-3}}{1.0865} = 0.0653$ secs

E.

$Z^2 = X_L^2 + R^2$

$X_L^2 = Z^2 - R^2$

$= (Z + R)(Z - R)$

Here $Z = \frac{V}{I} = \frac{195}{5} = 39$

$$X_L^2 = (39 + 1.280)(39 - 1.280)$$

$$= (40.280)(37.72)$$

$$= 1519.3616$$

$$X_L = \sqrt{1519.3616}$$

$$= 38.98$$

$$L = \frac{X_L}{2\pi f} = \frac{38.98}{377} = 103.13 \text{ mh}$$

Time constant $= \frac{103.13}{128} = 0.0807$ secs

2.3 Non-Linear Treatment

The mathematical analysis given in eqn. (10) on page 35 for the case of constant R and L cannot in general be applied to a circuit where L does not remain constant. This may be the case either in an iron clad circuit or an R and L circuit where the inductance core is saturated. The fact that L is variable makes both the co-efficients of eqn (1) variable.

The solution of such kind of differential equation is difficult. As a matter of fact the solution is impossible if the variation of L is not defined.

L being equal to $\frac{Nd\phi}{d_i}$ depends on the ϕ - i characteristics of the magnetic material that surrounds the L coil. The value of inductance therefore depends on the exact degree of magnetisation saturation of the surrounding magnetic material. Under any a - c condition the degree of saturation varies considerably with time and under transient conditions these variations are very often exaggerated. Referring to any typical B - H or ϕ - i curve will show that

$$L = \frac{N\,d\,\phi}{d_i}$$

is much greater over the straight portion of the curve than it is after the upper bend is reached.

Step-by-step method can be used for solving circuit problems involving variable parameters provided the exact variation of the parameters are known. Therefore in our case the variation of L is known if $\frac{N\,\phi}{i}$ characteristics of the surrounding magnetic material is known.

Substituting $L \frac{di}{dt}$ by $\frac{N\, d\phi}{dt}$ in eqn. (1)

the basic equation becomes.

$$N \frac{d\phi}{dt} + R\, i = E_m \; \text{Sin} \, (wt + \lambda) \tag{13}$$

where ϕ is expressed in webers if other quantities are expressed in practical units.

It $R\, i$ is negligible in comparism to $N \frac{d\phi}{dt}$ and if it is assumed that $\lambda = 0$.

then equation (13) becomes

$$N \frac{d\phi}{dt} = E_m \; \text{Sin} \; wt.$$

$$\phi = \frac{E_m}{N} \int \text{Sin} \; wt \; dt = - \frac{E_m}{wN} \, \text{cost} \; wt + C_1 \tag{14}$$

The constant of integration C_1 may be evaluated in terms of residual magnetism ϕ may be either positive or negative residual values at $t = 0$ and in most cases the residual magnetism is unknown. Therefore assuming $\phi = 0$ at $t = 0$ (unless max^m inrush current is to be determined)

$$0 = - \frac{E_m}{wN} + C_1 \;\; \therefore \;\; C_1 = \frac{E_M}{wN}$$

$$\phi = -\frac{E_m}{wN}\operatorname{Cos} wt + \frac{E_m}{wN}$$

$$\phi = \frac{E_m}{wN}(1 - \cos wt)$$

$$\phi = \phi_m (1 - \cos wt) \tag{15}$$

Since cos wt varies from -1 to + 1, it is therefore apparent that flux varies from zero at $t = 0$ to $2\phi_m$ at $t = \frac{T}{2}$.

The ordinary iron-core transformer with open secondary operate as simple iron-case RL circuit.

2.4 THE METHOD OF FINITE DIFFERENCE

The method of finite difference is usually employed in a circuit solution where the parameters are variable. This method involves step by step calculation. The step by step calculations are based on the fact that the parameters remain almost constant over the small finite internal of time. The circuit voltage and current are then assumed to remain constant over an arbitraty assigned increment of time t. Writing finite difference of ϕ and t, the equition (13) takes the form

$$N\frac{\Delta\phi}{\Delta t} + R_i = E_m \operatorname{Sin}(\Sigma\omega\Delta t + \lambda)$$

$$= E_m \operatorname{Sin}(\Sigma\Delta\rho + \lambda)$$

where $\Sigma \Delta \rho = \Sigma \omega \Delta t$, the angular displacement along the voltage wave of the point under investigation from the point of $t = 0$

$$\text{Let } E \ \text{Sin} \ (\Sigma \Delta \rho + \lambda) = e$$

$$\text{We have } N \frac{\Delta \phi}{\Delta t} + R\,i = e$$

$$\therefore \quad \Delta \phi = (e - Ri) \Delta t \quad \text{webers}$$

Calculating step by step the values of i can easily be found from ϕ - i curve. The datas may be tabulated in the following form.

Period	sec $\Sigma \Delta t$	degree $\Sigma \Delta \rho$	E_m $\sin \Sigma \Delta \rho$ volt	R_i	Kilo Lines $\Delta \phi$	Kilo Lines $\Sigma \Delta \phi$	i amperes

2.5 Determination of Phase angle at which Switching occurs:

From equation (10) we have

$$i = \frac{E_m}{Z} \sin(wt + \lambda - \theta) - \frac{E_m}{Z}(\lambda - \theta)\, e^{\frac{-Rt}{L}}$$

where $Z = \sqrt{R^2 + W^2 L^2}$, $\theta = \tan^{-1}\frac{wL}{R}$

At t = 0, the magnitudic of steady state and

transient current $= \frac{E_m}{Z} \sin(\lambda - \theta)$

Doubling effect occurs at $\lambda = 0$. but since from the photograph the peak is not double therefore we can say that switching has occured at certain value of λ. From the magnitude of the peak of the current wave of the photograph it appears that peak is 1.875 times of the normal peak.

Therefore we can say.

$$2 \sin(\theta - \lambda) = 1.875$$

$$\sin(\theta - \lambda) = 0.9375 = \sin 69.65°$$

$$\theta - \lambda = 69.65°$$

But $\theta = \tan^{-1}\frac{wL}{R} = \tan^{-1}\frac{(314)(100.34)\times10^{-3}}{1.719} = \tan^{-1}\frac{31.50676}{1.719}$

$= \tan^{-1} 18.328 = 86.90°$

$\therefore \theta = 86.90°$

$\therefore = \theta - 69.65° = 86.90 - 69.65° = 17.25°$

Hence transient occured at = 17.25°

SCHEMATIC DIAGRAM OF THE EXPERIMENTAL SETUP

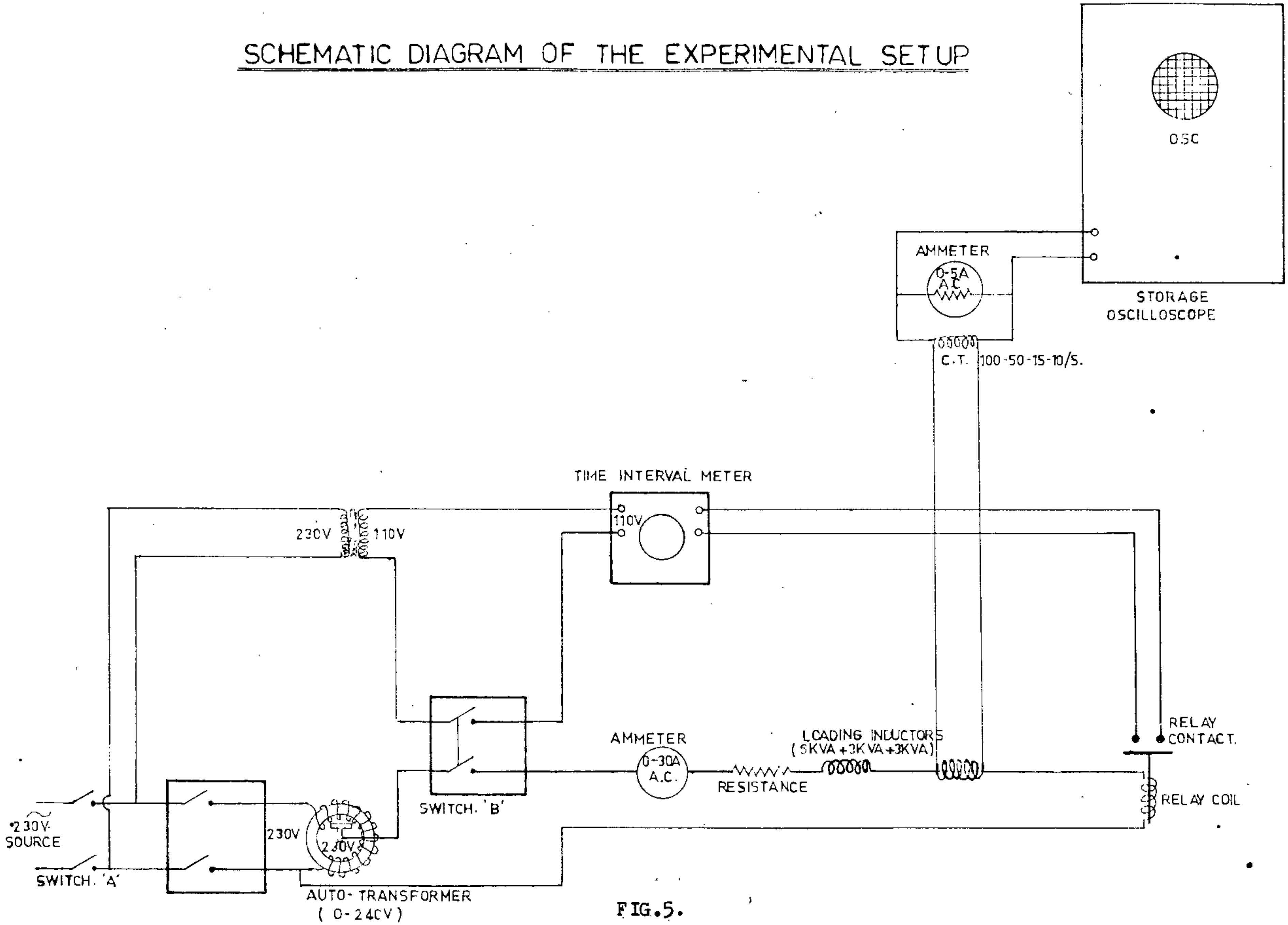


FIG.5.

CHAPTER - III

3. EXPERIMENTATION:

In order to determine the effect of transient on the operating time of a relay, a simple R-L circuit in series with the relay coil is used. Since the time constant of an R-L circuit depends on the ratio L/R the resistance is kept at minimum. In the experiment the resistance was the resistance of the coil itself and the resistance of the auto-transformer. To have a prominent transient wave of the current flowing through the R-L circuit three sets of loading inductors having rating 6 KVA and 3 KVA is connected in series of current wave shaps. Simultaneous recording was possible with the circuit as shown in the schematic line diagram Fig. 5. A storage oscilloscope and a time interval meter served the punpose of recording of transient occuring due to switching and measuring the time taken to operate the relay under different conditions respectively.

In order to differentiate the transient and non-transient operating time an auto-transformer which served the dual purpose of variable voltage source as well as the shunt inductance is used.

Since the value of the inductance was very high i.e. (about 6.67 henry), transient due to switching of switch A as shown in Fig. 5 has been almost fully suppressed and wave current flowing in the relay circuit were alsmost completely free from d.c.offset.

3.2 PROCEDURE:

(1) Relay has been checked. Time dial has been met in such a way that the gap is small.

(2) Storage oscilloscope has been calibrated.

(3) Connections have been made as shown in the line diagram.

(4) A low ampere measuring ammeter (0 - 5 A) has been connected in the secondary of the C.T. The input to the storage oscilloscope was connected to the ammeter terminal as shown in the line diagram.

(5) The auto-transformer has been adjusted so that at least a correct of 4.00 amperes flow in the circuit.

(6) Switch A has been operated for a number of times to get non-transient operating time as indicated by the Time Interval Meter.

(7) Switch B has been operated for a number of times to get the transient operating time as indicated by the Time Interval Meter.

(8) Transient and non-transient waves were stored by the storage oscilloscope and this still photographs of the wavesshape were taken with the help of oscilloscope camera.

3.3 MEASUREMENT OF TRANSIENT BY OSCILLOSCOPE:

The type 549 storage Oscilloscope of TETRONIX was used for the recording of transient waves occuring due to switching. A small signal (of the order of 0.05 V) has been given to the input terminal of channel A. Sensitivity knob has been set at 0.05 V/cm and the input selector switch to AC. The type 549 frontpanel controls has been set as follows:

HORIZONTAL DISPLAY	A
NORM - SINGLE SWEEP	NORM
A TIME / CM	50 m SEC
VARIABLE	CAL
STABILITY	PRESET
LEVEL	MID-RANGE

STORAGE CONTROLS

UPPER AND LOWER SCREEN STORAGE	OFF.
SCREEN SELECTOR	FULL
AUTO ERASE	OFF

1. Power switch is turned on.

2. INTENSITY,FOCUAS and ASTIG controls is adjusted for a well-defined display with nominal brightmen.

3. The diplay is positioned in the middle of the screen.

4. The LEVEL and STABILITY knob are adjusted in such a way that the display just disappears.

5. NORM - SINGLE SWEEP switch is set at PRESET position.

6. STORE bottons of UPPER SCREEN STORAGE and LOWER SCREEN STORAGE were preased for storing the display.

7. As the switch B of the schematic diagram (Fig.5) was operated the transient wave was stored and the photograph taken.

8. ERASE and RESET button is pressed, the stored display goes out.

9. The LEVEL and STABILITY knob is adjusted (if needed) for next transient display.

10. Switch B of the schematic diagram (Fig. 5) is again operated, the transient wave is stored again and the photograph taken. The process is repeated for different transient and non-transient displays.

CHAPTER - IV

RESULTS:

4. INTRODUCTION: In any R-L circuit transient operating time of a relay can easily be found out by simply switching on/off the switch with the help of a TIM. But non-transient operating time for a relay in a series R-L circuit is difficult to find out because any switching is always associated with transient or D.C. offset. In order to have the operating time for a steady state value of the current we must eliminate the transient from the circuit. This has been done in our case by using an iron-core voltage regulator which has got a very high value of inductance. This induction has served the purpose of a shunt inductance which in turn has suppressed the transient. Therefore when switch A used before the voltage regulator is closed the current flowing in the relay coil is almost free from transient wave or D.C. offset. The experimental results of using the voltage regulator in shunt on operating time has been shown in Table 1. The operating time of the same relay without using the voltage regulator has been shown in Table 2.

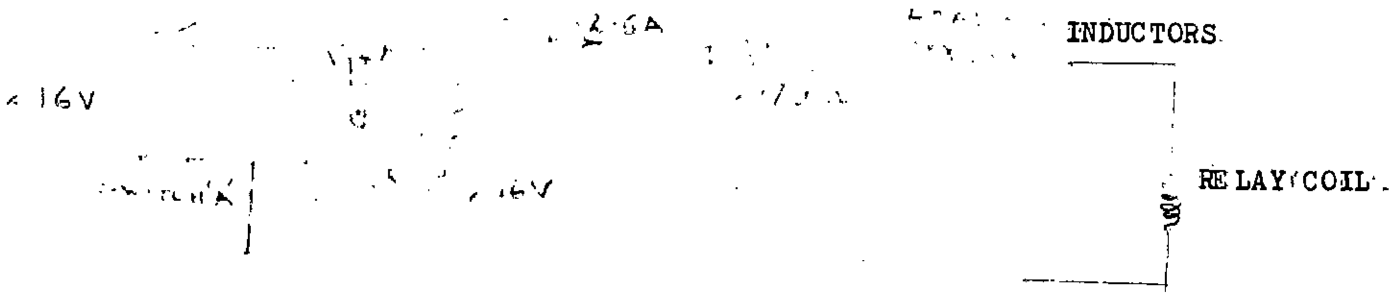


FIG 6.

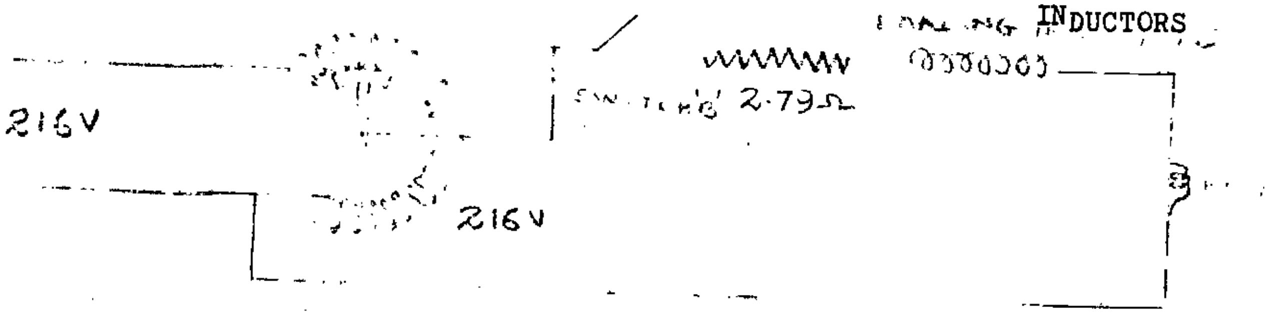


FIG 7.

When switch A has been used the standard deviation of the operating times of the relay is only 0.0227. On the other hand the standard deviation of operating times of the relay when switch B has been used is 0.0521. This value of standard deviation is near to 0.0548 when the voltage regulator has not been used at all. This is therefore the transient operating time. The different photographs of the voltage wave as stored by the storage oscilloscope also confirms the above statement.

TABLE 3 shows that the minimum transient operating time is 0.83 sec and the maximum transient operating time is 0.915 sec. The photographs of Plate 1, No.1 and 3 of page 102 show that the peak of the transient is 175.6% in the former case and the peak of the transient is 128.1% in the second case. The standard deviation of transient operating time for ten number of such switching is 0.0258 which is about 4.3 times than the standard deviation of non-transient operating time i.e. 0.00603 . The variation of non-transient operating time for eleven number of switching is quite small. The minimum value is 0.92 sec and the maximum value is 0.94 sec. Although theoretically for a steady state value, the operating time of the relay should have been the same in all cases but the slight difference in operating time is mainly for two reasons, namely a little bit of transient exists even after the suppression of the transient by the voltage regulator. The 2nd reason is the fact that the recording instrument namely time interval meter has got its own error. Further more TIM (Time Interval Meter) being an electro mechanical device the error therefore is not very small. Use of an electronic device in this case would have given a far better result and the difference in maximum and minimum value of non-transient operating time would have been narrower. The smallest value of division in the TIM is 10 m sec. Eye estimation has been made on a number of readings which are not free from errors.

Similarly for different set of inductive value standard deviations for transient operating time and non-transient operating time are 0.0183 and 0.00749 (Table 4A). The difference in different value of transient operating time is due to phase angle at which switching occurs. Switching at different phase angle causes different peak value of transient wave which in turn is responsible for different value of operating time of the relay. Table 4B to 7 gives different values of standard deviation for transient and non-transient operating time.

Switching at different angle has given different types of transients having different peaks. The greater the peak the greater is the transient or D.C. offset. The greater is the peak of the transient smaller is the operating time of the relay, hence peak value of the transient is most important in our case. Theoritically it has been shown in Chapter-II that the maximum transient can be 200% the steady state value. From the photographs of transients we have been that the maximum peak has been 187.5% i.e. switching has occured at angle 17.25%. Switching at zero angle of phase is impossible in practical cases.

Peak values of transients have been divided into two parts (i) positive peak and (ii) negative peaks. Two different OGIVE CURVES have been plotted for positive and negative peak respectively. All the peaks have been arranged in descending order of its value. The number of times it has occured has been counted and a table has been prepared. Comulative frequency of occurance has been calculated and table tabulated as shown in Table VIIIA and TableVIIIB of the Appendix.

Peak Vs cumulative frequency has been plotted in Fig. 16 and Fig. 15 for positive and negative peaks. From Table VIIIA & VIII B it is clear that 174.3% of negative peak has occured 9 times and positive peak of 174.3 has occured 4 times. It can therefore be said that for 174.3 % peak has occured maximum number of times & therefore due consideration should be taken in the design and co-ordination of a relay for 174.3% transient.

Plate 1 gives the photographs of non-transient and transient wave shapes of the current flowing in the circuit in series with the relay coil. The value of the internal resistance of the coil was 1.412 ohms, and the inductance calculated as shown in the aricle 2.2A was 126.6 mH. The internal resistance of the voltage regulator was 0.490 ohms. The applied voltage and the current flowing through the relay coil were 225 V and 4.7A respectively. Pages 99 to 101 contain the photographs of the wave shape of the current flowing through the relay coil when switch A is operated i.e. non-transient operation. (as shown in the schematic diagram of Fig. 5) The speed and sensitivity were 0.10 sec/cm and 0.05 V/cm respectively. The relay operating time for non-transient operations are shown below the photographs respectively. Page 102 to 103 contain the wave shapes of the current flowing through the circuit under the same conditions as above when switch B was operated i.e. transient operation. Speed, sensitivity, relay operating time and the peak of the transient wave in terms of percent of the steady state value of the current are also mentioned respectively under each photographs as shown in the plate 1 from page 102 to 103 . The operating times, its mean value and the standard deviations for transient and non-transient operating times are given in Table 3.

Plate 2A gives the photographs of transient and non-transient wave shapes of the current flowing through an R-L circuit in series with the relay coil. The value of the internal resistance of the three loading inductors was 1.229 ohms. The inductance calculated as shown is article 2.2B was 100.34 mH. The applied voltage and the current flowing through the circuit were 235 V and 6A respectively. Pages 104 to 106 contain the photographs of the wave shapes of the current flowing through the relay coil when switch B was operated i.e. transient operation (as shown in the schematic diagram of Fig. 5). The speed and the sensitivity were 50 m sec/cm and 0.05 V/cm. The speed, sensitivity, relay operating time and transient peaks in terms of the percent of the steady state valuesare shown below each photo. Page 107 to 109 contain the wave shapes of the current flowing through the relay circuit under the same conditions as above when switch A was operated i.e. non-transient operation. Speed, sensitivity and relay operating time are shown below each photograph. The operating time for transient operation and non-transient operation are shown in Table 4A. Arithmetic means and standard deviations of the operating times for transient and non-transient operations are shown in the same Table.

Plate 2B gives the photographs of transient and non-transient wave shapes of the current flowing through the relay coil. The value of the internal resistance was 1.412 ohms and the inductance calculated as shown in article 2.2A was 126.6 mH pages 110 to 111 give the photographs of the wave shapes of the current flowing through the relay coil when switch B was operated i.e. transient operation (as shown in the schematic diagrams of Fig. 5). The speed and sensitivity are 50 m sec/cm and 0.05 V/cm. The relay operating time and peak of the transient in terms of percent of the steady state value are shown below each photograph. Page 113 to 115 give the wave shapes of the current flowing through the relay circuit under the same conditions as above when switch A was operated i.e. non-transient operation. Speed, sensitivity and relay operating time are shown below each photo. The operating time for transient and non-transient operations, its means and standard deviations are shown in Table 4B.

Plate 3A gives the photographs of the wave shapes of transient and non-transient current flowing through the relay coil. The value of the internal resistance of the inductive coil was 1.229 ohms and the inductance calculated as shown in article 2.2B was 100.34 mH. The internal resistance of the voltage regulator was 0.490 ohms. The applied voltage and the current flowing through the relay circuit

circuit were 180 V and 4.5 A. Page 116 to 116 contain the photographs of the wave shapes of the current flowing through the relay coil when switch B was operated i.e. transient operation (as shown in the schematic diagram of Fig.5). The speed and sensitivity of the oscilloscope were 50 m sec/cm and 0.05 V/cm. The relay operating times and the peaks of the transient in percent of the steady state value are shown below each photo page 117 to 119 give the wave shapes of the current flowing through the circuit under the same conditions as above when switch A was operated i.e. non-transient operation. Speed, sensitivity and the relay operating time are shown below each photo. The operating times, its mean values and the standard deviations for transient and non-transient operations are shown in Table 5A.

Plate 3B gives the photographs of the wave shape of the transient and non-transient current flowings through the relay coil. The value of the internal resistance of the inductive coil was 1.008 ohms and the inductance calculated as shown in article 2.2C was 126.5 mH. The applied voltage and the current flowing through the relay circuit were 240 V and 5A respectively page 120 to 120 contain the photographs of the wave shape of the current flowing through the relay coil when switch B was operated i.e. transient operation. The speed and sensitivity were 50 m sec and 0.05 V/cm. The relay operating times

Of the transieht in percent of the steady state values are shown below each photo. Page 121 to 123 give the wave shapes of the current flowing through the circuit under the same conditions as above when switch A is operated i.e. non-transient operation. Speed, sensitivity of the oscilloscope and the relay operating time are shown below each photo. The operating times, its means values and and standard deviations for transient and non-transient operations are shown in Table 5B.

Plate 4 gives the photographs of the transient and non-transient wave shapes of the current flowing through the relay coil. The valueof the internal resistance of the inductance coil was 0.5965 ohms, and the inductance calculated as shown in article 2.2D was 70.93 mH. The applied voltage and the current flowing through the R-L circuit in series with the relay coil were 210 V and 8A. Page 124 to 125 contain the photographs of the waveshapes of the current flowing through the relay coil when switch B was operated i.e. transient operation. The speed and the sensitivity of the oscilloscope were 50 m sec and the peaks of the transient in percent of the steady state value are shown below each photograph. Page 126 to128 give the waveshapes of the current flowing through the circuit under the same conditions as above.

when switch A is operated i.e. non-transient operation. Speed, sensitivity of the oscilloscope and the relay operating time are shown below each photographs. The operating times, its mean values and standard deviations for transient and non-transient operations are shown in Table 6.

Plate 5 gives the photographs of the waveshaps of transient and non-transient current flowing through the relay coil. The value of the internal resistance of the inductive coil as 0.790 ohms and the inductance calculated as shown in article 2.2 E was 103.13 mH. The applied voltage and the current flowing through the relay circuit were 195 V and 5A respectively. Page 130 to 132 give the photographs of the waveshaps of the current flowing through the relay coil when switch B was operated, i.e. transient operation. The relay operating times and the peaks of the transient in percent of the steady state value are shown below each photograph. Page 129 to 129 give the waveshapes of the current flowing through the circuit under the same conditions as above when switch A was operated i.e. non-transient operation. Speed, sensitivity of the oscilloscope and the relay operating time are shown below each photograph. The operating times, its mean value and the standard deviations for transient and non-transient operations are shown in Table 7.

5.1 DISCUSSIONS: An R-L circuit in series with the relay coil had been used to give a prominant transient wave shape of the current flowing through the relay coil circuit. The resistance R is the internal resistance of the variable loading inductors used. The measurement of internal resistance of the coil x had been done with the help of a wheatstone bridge. The value of resistance measured were not free from errors. The value of variable inductors used was measured by volt-ampere method. The exact value of inductance used in the experiment was not known. Therefore its measurement by volt ampere method were also not free from errors. Since we did not use any external resistance, we had to use a C.T., A low resistance ammeter had been connected across the secondary of the C.T. This serviced double purpose of suppressing C.T. transients if any to distort the main transient in thx circuit. Secondary, a low voltage drop was possible (of the order of 0.05 V) which was given as on imput signal to the storage oscilloscope. The transients thus measured cannot be said to be 100% free from C.T. transients. The switches used in our experiments were mechanical and old. The contacts due to on/and off of such switches did not give perfect connection or disconnection. This is evident from photographs of page 116 and 125.

The disconnection in the middle of the transient wave was due to imperfect contact of the mechanical switch 'B' of the schematic diagram of Fig. 5. These had been some over shoots as can be seen from the photographs of page 121 . These overshoots may be attributed to imperfects contact of switch 'A'.

Time intefval meter had been used to measure operating time of the relay. The device was an electro-mechanical one and therefore errors had crepts in the measurement of operating time. Had we used an electronic device the response would have been far more quick. Furthermore the minimum time measured with this device was 10 m sec. Therefore our measurements of operating time could not be accurate. An electronic device would have given a more accurate results.

The relay used for experimental purpose was an overcurrent relay. It does not operate below 4 ampere. This was another limitation of the experiment. Had the relay been operatable below 4 ampers we could have used more loading inductors for more better transients. Furthermore the voltage regulator could not give more than 235 V. The higher the inductance value the lower is the circuit current. The circuit current below 4 ampere would not operate the relay.

Lowering the inductance would not give a better transient. These were the limitations of the experiments. For better results we need a high range voltage regulator.

For our experimental purposes we had used an overcurrent relay having operating range for current 4-16 ampher. A fast relay with low range of current would give remarkable difference in operating time for transient and non-transient operations.

Table 1 gives remarkable difference in operating time when switch 'A' and switch 'B' were used. (as shown in scrematic diagram of Fig. 5). The arithmetic mean for twenty sets of reading of operating time for a particular gap setting of the relay was 2.57 sec, when switch 'A' is used. The arthmetic mean for similar readings when switch 'B' was used was 2.496 secs. This we called it transient operating time.

Table 2 gives the sets of readings of operating time when no regular had been used. The arithmatic mean in this case was 2.50 secs which was very mean to 2.496 secs when switch 'B' was operated.

Table 3 gives ten sets of roading when switch 'B' was used as 2.496 secs. This we called it transient operating time.

Table 2 gives the sets of reading of operating time when no regulator had been used. The arithmetic mean in this case was 2.50 secs which was very mean to 2.496 secs when switch 'B' operated.

Table 3 gives ten sets of reading when switch 'B' was operated the arithmetic mean was 0.865 sec and the standard deviation 0.0258.

Operation of switch 'A' gave eleven such settings. The arithmatic mean and the standard deviations were 0.93 sec and 0.00603 respectively. The effect of transient on the operating time is therefore quite prominent i.e. an early operation of the relay by 0.065 sec. The inductance and the resistence in the circuit used were 126.6 mH and 1.412 ohms respectively.

Table 4A and 4B gave another sets of reading for transient and non-transient operation. The arithmetic means of ten sets of reading are 0.880 sec and 1.071 sec respectively. Transient operation therefore actuals the relay 0.191 sec earlier. Standard deviations are 0.0237 and 0.007 respectively.

This clearly shows that the variation in operating t transient operation is appreciable in comparison to th in operating time for non-transient operation. This is du that switching occurs at different value of phase angle whic gives different peaks of transients the higher the peak of transient, lower is the operating time.

Table 5A and 5B givesn another sets of operating time for transient and non-transient operation. Here the inductance and resistance have got values 100.34 mH and 1.719 ohms respectively in the circuit. Arithmatic means of operating times for transient and non-transient operation No.1 .90 sec and 1.973 respectively. The difference in operating time of the mean values is 0.073 sec. standard deviations are 0.0219 and 0.00781 respectively. For Table 5B where the industance and resistance used were 126.6 mH and 1.498 ohms respectively. The airthmatic means are 1.433 sec and 1.529 sec respectively for transient and non-transient operation. The difference in the mean values of operating time is 0.096 sec . Standard deviations are 0.0195 and 0.011 respectively.

Similarly for Table 6 and 7 where inductance and resistance used were 70.93 mH, 1.0865 ohms. 103.13 mH and 1.280 ohms respectively, the mean operating time for transient operations were 0.650 sec and 0.34 sec and for non-transient operations were 0.708 sec & 0.4295 sec respectively. The transient operation in the two cases actuals the relay 0.058 sec and 0.0895 sec earlier. Plate 1 gives eight photographs of the transient operation of the relay in series which the circuit where inductance and resistance had been 126.6 mH and 1.902 ohms respectively. The maximum and minimum current peaks were + 175.6% and + 128.1% of the normal steady state value respectively.

In plate 2A photograph No. 6 gives a transient where peak is -185.7% of the normal steady state value. It can easily be seen that transient persists for quite a few cycle i.e. about 6 cycles. In the same plate photograph No.4 gave a tail which way due to imperfect contact of the switch. Similar tail had occured in few more places in the non-transient operation of the relay. All these had been due to imperfect switch contact.

In Plate 3A photograph No.3 gave a separation in the middle of the transient wave. This was due to imperfect contact of the switch. The peak of the transient was + 187.5% of the normal steady state value. The inductance and resistance used were 100.34 mH and 1.719 ohms respectively. The operating time had been 1.86 sec. This was the minimum operating time for the same set of readings as shown in Table 5A.

Tables 9 to 15 (Page 92 to 98) gives the relationship of the transient occurence angle and the operating time of the relay. The calculations of transient occurence angle have been shown in the tables from IX to XV of the Appendix. The transient occurence angle ' λ ' and the corresponding operating time of the relay has been plotted in the graphs from page 71 to page 77. It is quite clear that the relationship is non-linear and similar to magnetization curve. This is quite evident in view of the fact that relay has got a magnetic cone through which the current responsible for the operation of the relay passes. Transient operation of the relay has reduced the operating time from 3.6% to 20.8% as shown in the Appendix XVI.

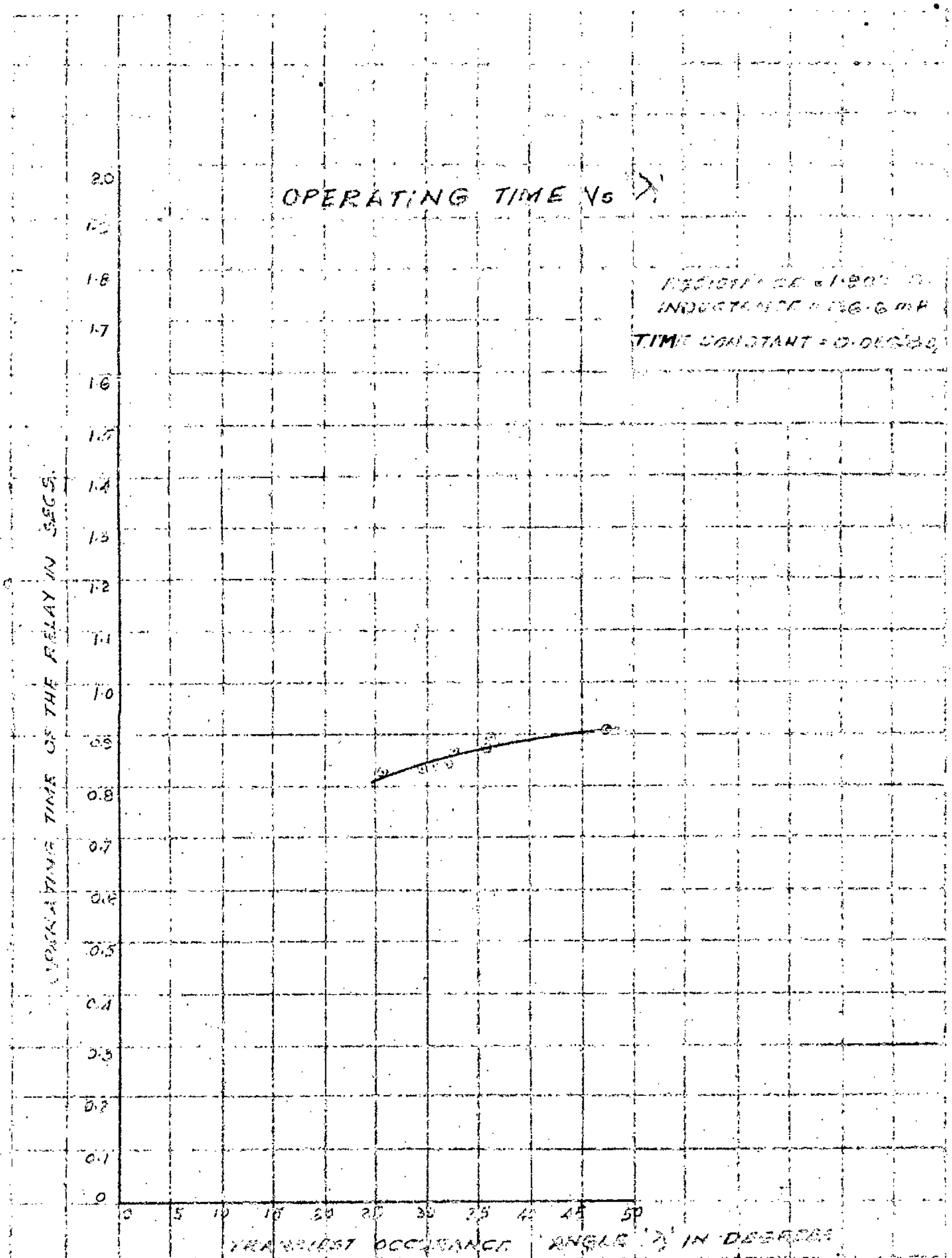
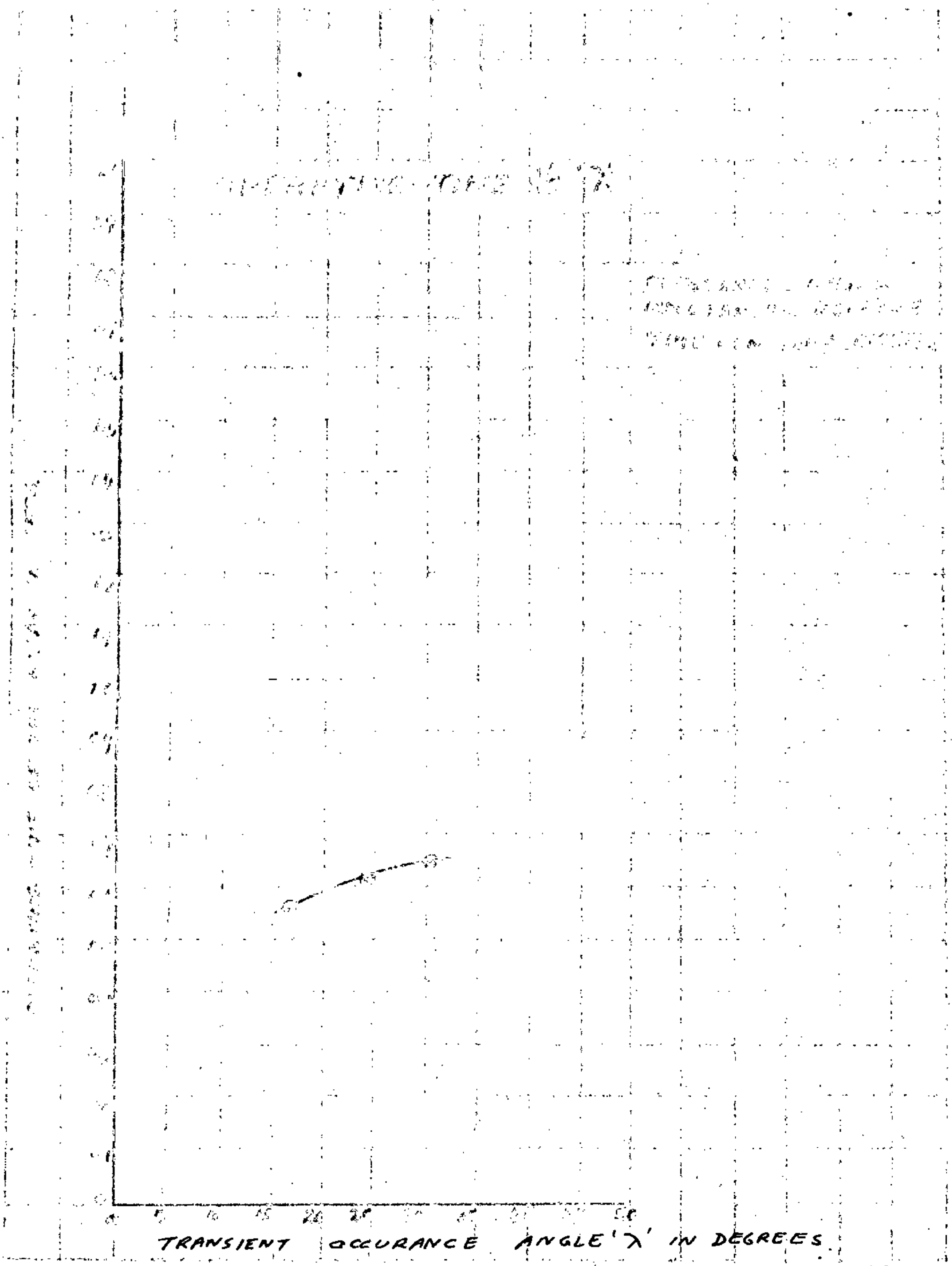

OPERATING TIME Vs λ
TIME CONSTANT
OPERATING TIME OF THE RELAY IN SECS.
TRANSIENT OCCURANCE ANGLE 'λ' IN DEGREES
2.0
1.8
1.7
1.6
1.4
1.2
1.1
1.0
0.8
0.7
0.5
0.4
0.1
0
0
5
10
50

FIG.8.



. FIG.9.

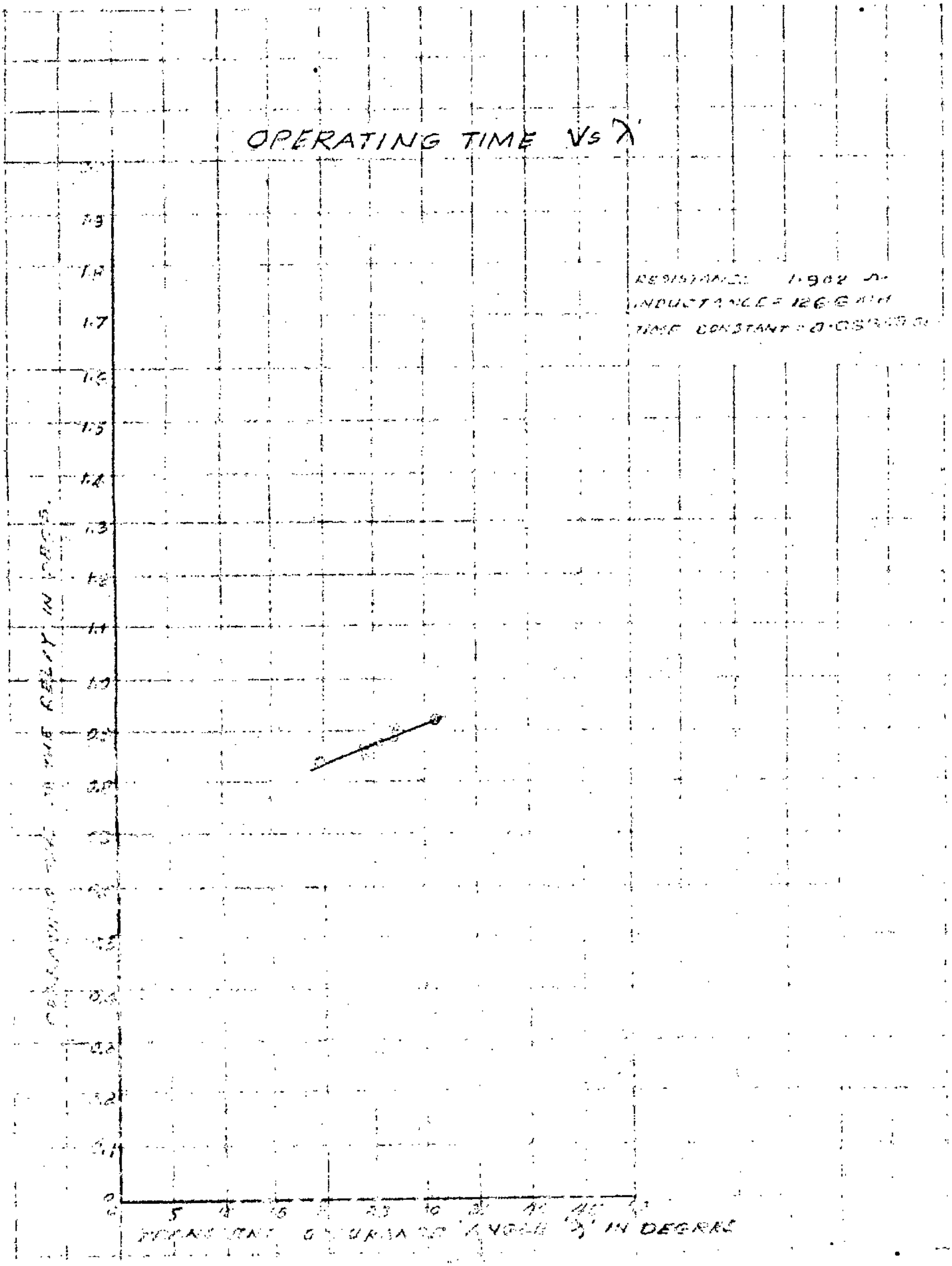


FIG.10.

OPERATING TIME Vs 'λ'

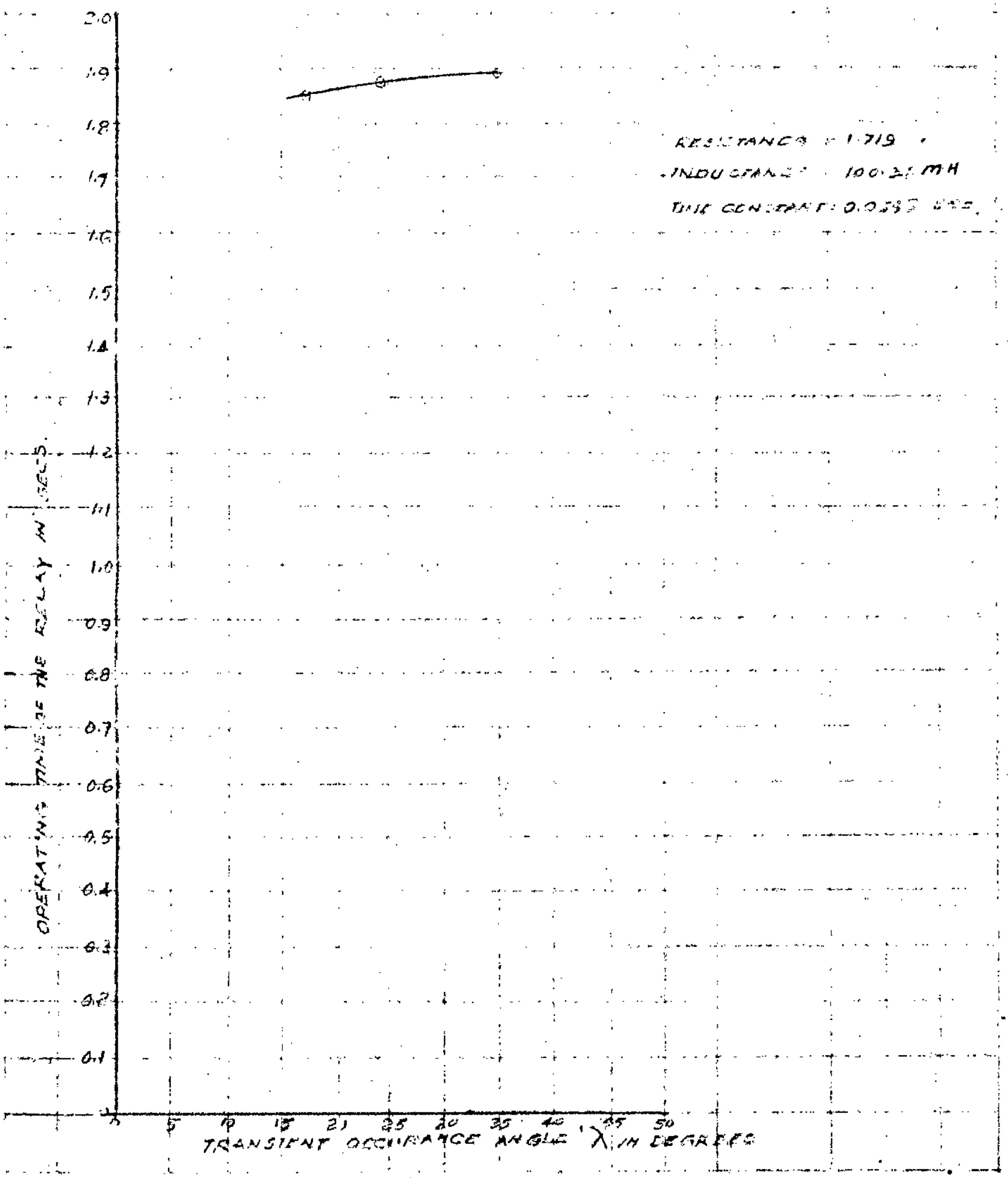


FIG.11.

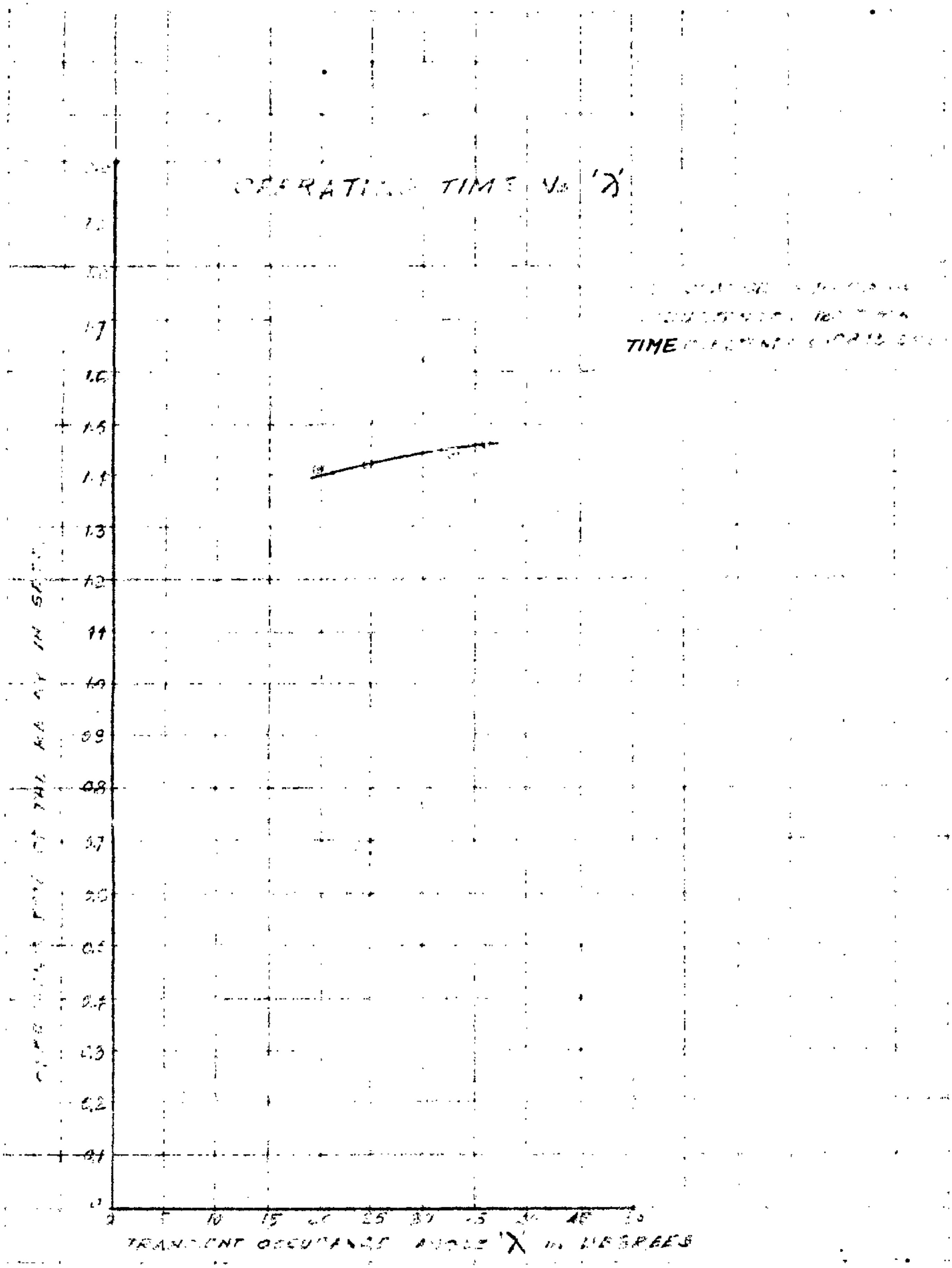


FIG. 12.

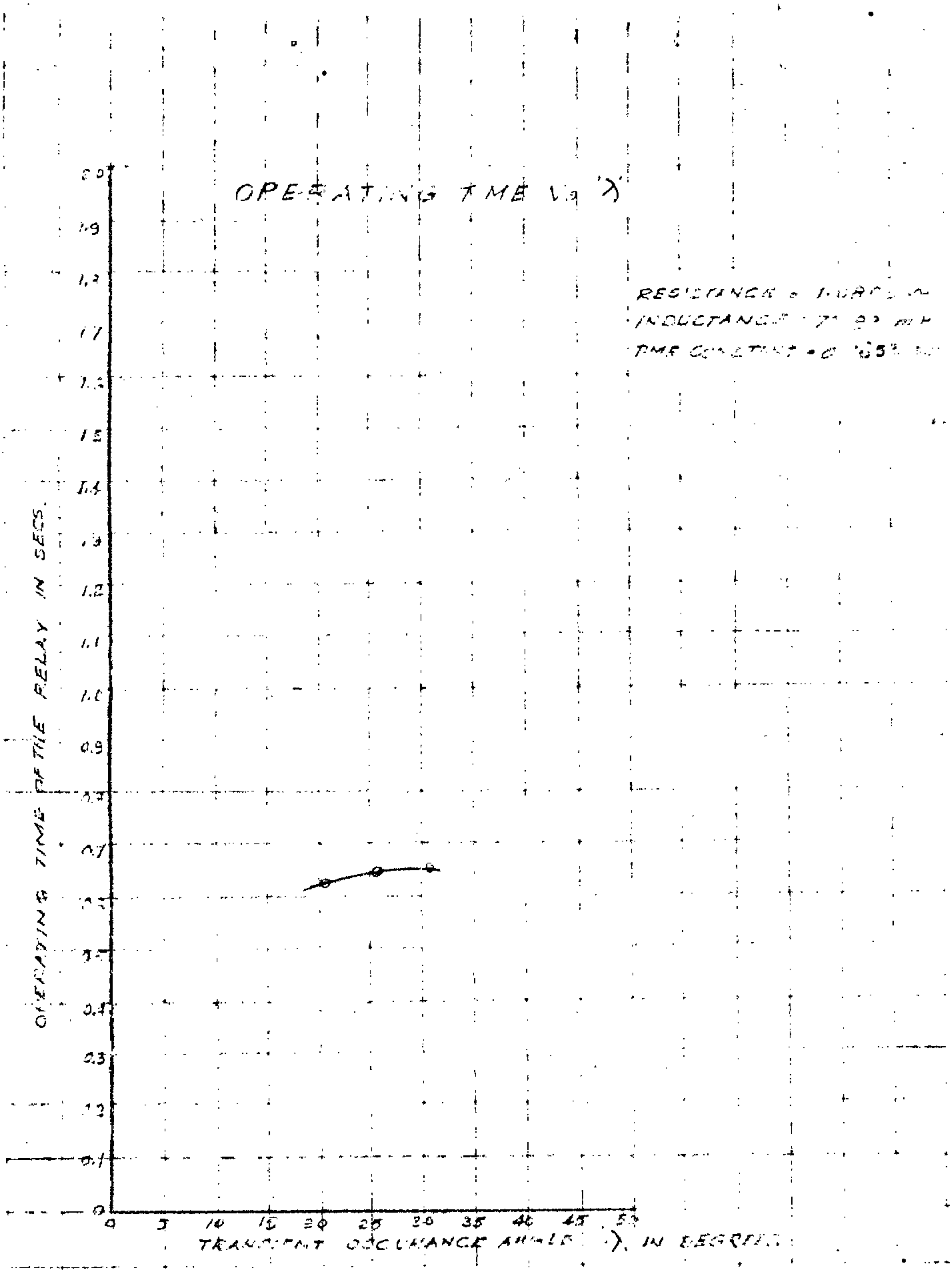

OPERATING TIME Vs λ
OPERATING TIME OF THE RELAY IN SECS.
TRANSIENT OCCURANCE ANGLE λ IN DEGREES

FIG.13.

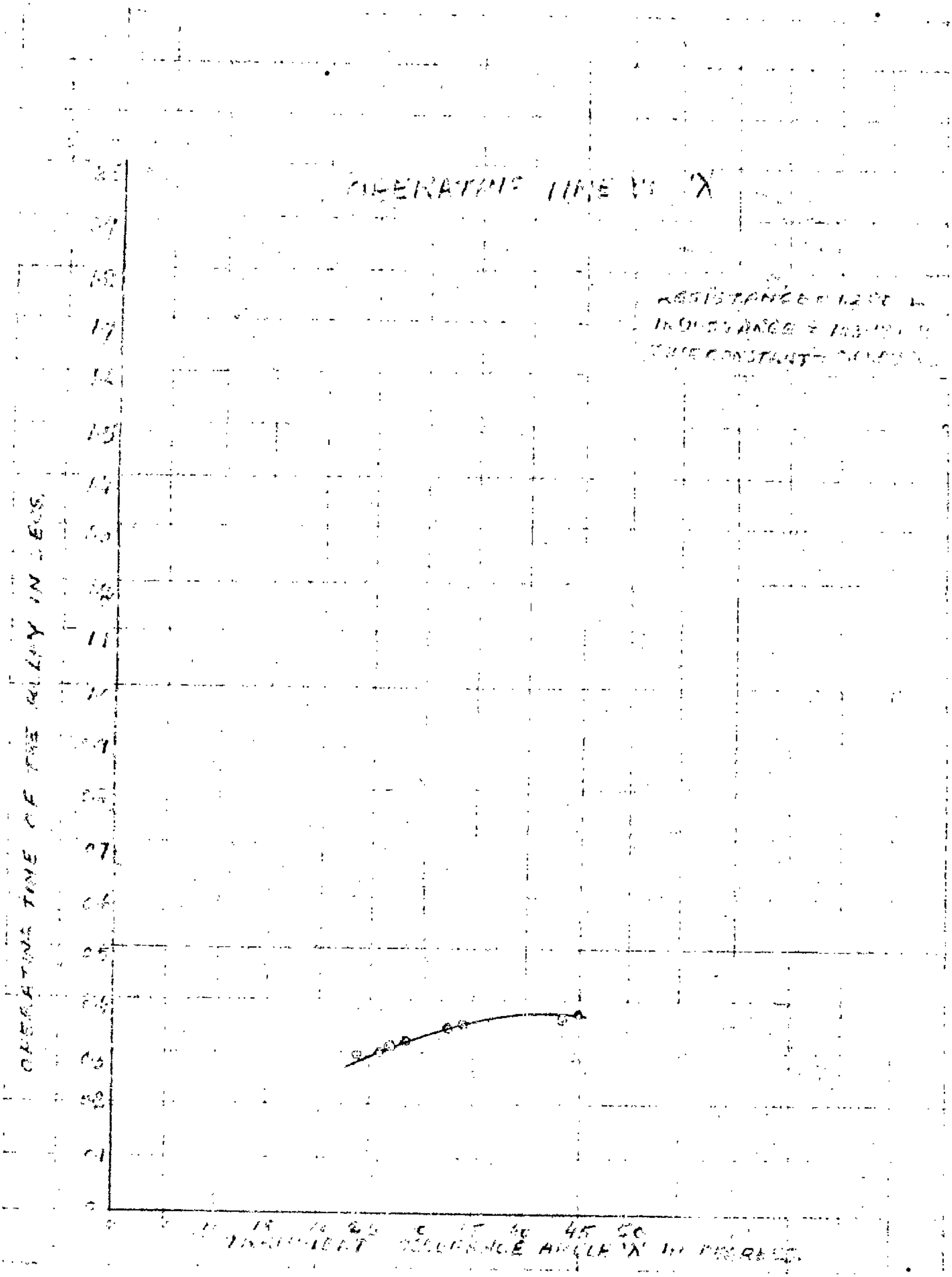


FIG.14.

5.2 CONCLUSIONS:

Transients current waves have been obtained using loading inductors and its internal resistance in series with the coil of an over current relay. Transient and non-transient operating times of the relay have been obtained. Photographs of different types of transients and non-transients have been taken. Operating times for transient and non-transient operations have been recorded simultaneously by a time interval meter. Analytical expressions have been developed for the transient current. A comprehensive analyses of the experimental results is given.

It is seen from the two ogive curves that the number of switching faults exceeding 180% of maximum peak value of current are very few. Almost all the peaks of the transients of the faults considered were therefore obtained between 125% to 180% of the maximum peak value and data obtained can therefore be considered to be based on randomly occuring faults with respect to λ, the angle at which faults occur.

Experimentaly it has been found that a non-linear relation exists between operating time of the relay and the angle of occurance of the transient ' λ ' . From the nature of the curves it appears to be similar to the usual magnetization curves of magnetic materials. This seems to be as expected, in view of the fact that the relays have magnetic materials as cores which are magnetized by the operating coils through currents proportional to the transient currents in the circuit. However the d.c. component of transient currents would give rise to various degrees of saturation for each fault, and therefore the point of the saturation curve at which the relay actually operates for each transient would be variable. The exact nature of non-linearity and the correlation of actual operating times considering degrees of saturation and the magnitudes of current peaks needs careful investigation in order to establish the operating characteristics of very fast relays under transient conditions.

It is observed that power system transients due to switching on/off the load affect the operating time of the over current relay considerably.

Further work may be done by taking into account of shunt capacitance. The experimental work has been limited to one overcurrent relay only. More works may therefore be done using different types of relays.

NEGATIVE PEAK TRANSIENT
OGIVE CURVE

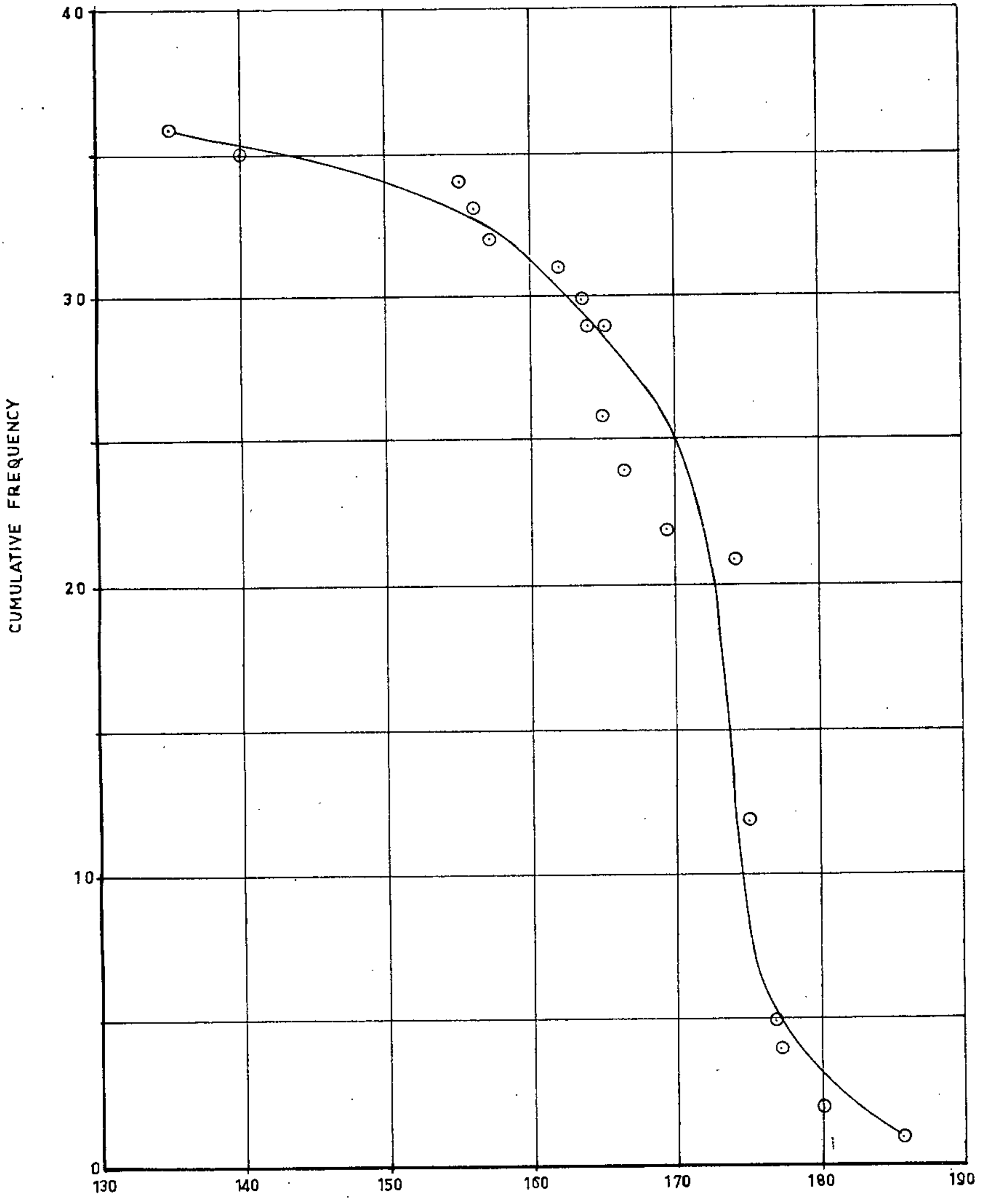


FIG.15

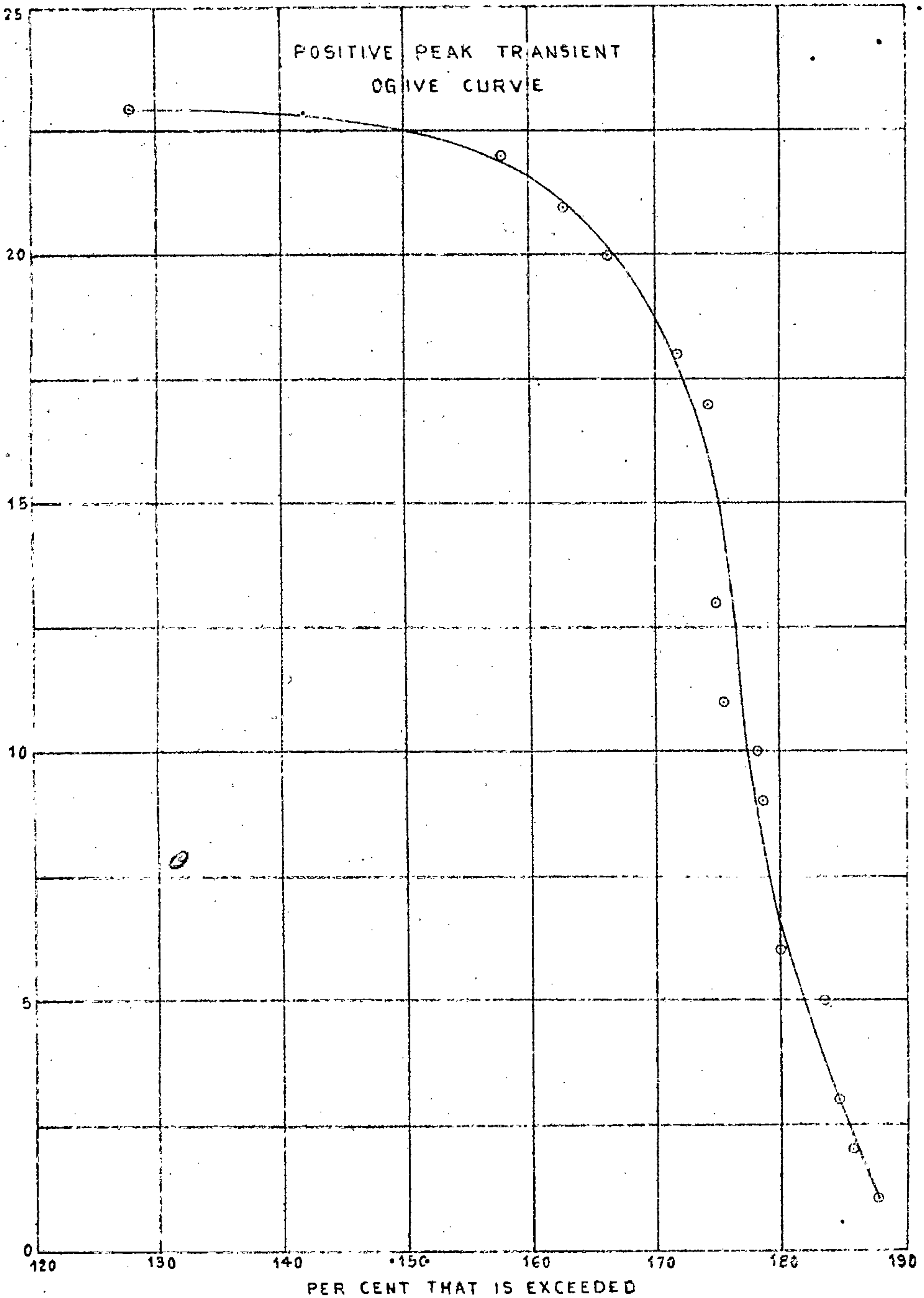

POSITIVE PEAK TRANSIENT
OGIVE CURVE
25
20
15
10
5
0
120
130
140
150
160
170
180
190
PER CENT THAT IS EXCEEDED

TABLE -I

Sl. No.	Operating time of the relay when switch A is closed (with voltage regulators).	Sl. No.	Operating time of the relay when switch B is closed (with voltage regulators)
1.	2.54 sec.	1.	2.50 sec.
2.	2.54 ,,	2.	2.48 ,,
3.	2.565 ,,	3.	2.445 ,,
4.	2.575 ,,	4.	2.58 ,,
5.	2.57 ,,	5.	2.49 ,,
6.	2.60 ,,	6.	2.455 ,,
7.	2.58 ,,	7.	2.585 ,,
8.	2.56 ,,	8.	2.47 ,,
9.	2.585 ,,	9.	2.495 ,,
10.	2.60 ,,	10.	2.45 ,,
11.	2.59 ,,	11.	2.43 ,,
12.	2.58 ,,	12.	2.50 ,,
13.	2.595 ,,	13.	2.58 ,,
14.	2.57 ,,	14.	2.56 ,,
15.	2.565 ,,	15.	2.54 ,,
16.	2.575 ,,	16.	2.56 ,,
17.	2.56 ,,	17.	2.445 ,,
18.	2.53 ,,	18.	2.45 ,,
19.	2.52 ,,	19.	2.445 ,,
20.	2.60 ,,	20.	2.44 ,,

Arithmetic Mean = $\bar{X}$ = 2.57
Standard deviation
= σ = 0.0227

Arithmetic Mean = $\bar{X}$ = 2.496
Standard deviation
= σ = 0.0521

T A B L E - 2

Sl.No.	Operating time of the relay (without voltage regulator)
1.	2.45 sec.
2.	2.49 ,,
3.	2.44 ,,
4.	2.48 ,,
5.	2.55 ,,
6.	2.50 ,,
7.	2.50 ,,
8.	2.58 ,,
9.	2.53 ,,
10.	2.59 ,,
11.	2.43 ,,
12.	2.55 ,,
13.	2.45 ,,
14.	2.47 ,,
15.	2.43 ,,
16.	2.45 ,,
17.	2.43 ,,
18.	2.56 ,,
19.	2.58 ,,
20.	2.54 ,,

Arithmetic Mean = $\bar{X}$ = 2.50

Standard deviation = σ = 0.0548

TABLE - 3

Sl.No.	Operating time of the relay for transient operation.	Sl. No.	Operating time of the relay for non-transient operation.
1.	0.83 sec.	1.	0.935 sec.
2.	0.88 ,,	2.	0.935 ,,
3.	0.915 ,,	3.	0.93 ,,
4.	0.90 ,,	4.	0.93 ,,
5.	0.845 ,,	5.	0.94 ,,
6.	0.84 ,,	6.	0.93 ,,
7.	0.87 ,,	7.	0.92 ,,
8.	0.85 ,,	8.	0.935 ,,
9.	0.85 ,, (exposed)	9.	0.94 ,,
10.	0.87 ,, ,,	10.	0.93 ,,
~~11x~~		11.	0.935 ,,

Arithmetic Mean = $\bar{X}$ = 0.865

Standard deviation

= σ = 0.0258

Arithmetic Mean = $\bar{X}$ = 0.93 sec.

Standard deviation

= σ = 0.00603

T A B L E - 4A.

Sl. No.	Operating time of the relay for transient operation.	Sl. No.	Operating time of the relay for non-transient operation.
1.	0.66 sec.	1.	0.69 sec.
2.	0.625 ,,	2.	0.68 ,,
3.	0.625 ,,	3.	0.69 ,,
4.	0.63 ,,	4.	0.68 ,,
5.	0.625 ,,	5.	0.69 ,,
6.	0.58 ,,	6.	0.68 ,,
7.	0.63 ,,	7.	0.67 ,,
8.	0.63 ,,	8.	0.67 ,,
9.	0.63 ,,	9.	0.68 ,,
10.	0.625 ,,	10.	0.69 ,,

Arithmetic Mean $= \overline{X} = 0.626$

Standard deviation

$= \sigma = 0.0183$

Arithmetic Mean $= \overline{X} = 0.682$

Standard deviation

$= \sigma = 0.00749$

TABLE -4B

Sl. No.	Operating time of the relay for transient operation.	Sl. No.	Operating time of the relay for non-transient operation.
1.	0.87 sec	1.	1.07 sec.
2.	0.84 ,,	2.	1.06 ,,
3.	0.90 ,,	3.	1.06 ,,
4.	0.86 ,,	4.	1.07 ,,
5.	0.89 ,,	5.	1.08 ,,
6.	0.85 ,,	6.	1.07 ,,
7.	0.88 ,,	7.	1.08 ,,
8.	0.89 ,,	8.	1.08 ,,
9.	0.90 ,,	9.	1.07 ,,
10.	0.92 ,,	10.	1.07 ,, (exposed)

Arithmetic Mean = $\bar{X}$ = 0.880

Standard deviation

= σ = 0.0237

Arithmetic Mean = $\bar{X}$ = 1.071

Standard deviation

= σ = 0.007

TABLE - 5A

Sl. No.	Operating time of the relay for transient operation.	Sl. No.	Operating time of the relay for non-transient operation.
	sec.		
1.	1.92 (exposed)	1.	1.97 sec.
2.	1.89 sec ,,	2.	1.98 ,,
3.	1.92 ,, ,,	3.	1.96 ,,
4.	1.90 ,, ,,	4.	1.97 ,,
5.	1.87 ,, ,,	5.	1.98 ,,
6.	1.885 ,, ,,	6.	1.98 ,,
7.	1.895 ,, ,,	7.	1.98 ,,
8.	1.86 " ,,	8.	1.97 ,,
9.	1.88 " ,,	9.	1.98 ,,
10.	1.88 " (exp)	10.	1.96 ,,

Arithmetic Mean = $\bar{X}$ = 1.90

Standard deviation

= σ = 0.0219

Arithmetic Mean = $\bar{X}$ = 1.973

Standard deviation

= σ = 0.00781

TABLE - 5B

Sl. No.	Operating time of the relay for transient operation		
1.	1.46	sec.	
2.	1.44	,,	
3.	1.41	,,	
4.	1.42	,,	
5.	1.40	,,	(exposed)
6.	1.46	,,	,,
7.	1.42	,,	,,
8.	1.44	,,	,,
9.	1.43	,,	,,
10.	1.45	,,	,,
11.			

Arithmetic Mean = $\bar{X}$ = 1.433 sec

Standard deviation = 0.0195

Sl. No.	Operating time of the relay for non-transient operation.		
1.	1.55	sec.	
2.	1.54	,,	
3.	1.54	,,	
4.	1.52	,,	(exposed)
5.	1.535	,,	,,
6.	1.535	,,	,,
7.	1.54	,,	,,
8.	1.54	,,	
9.	1.52	,,	
10.	1.52	,,	
11.	1.52	,,	(exposed)
12.	1.54	,,	
13.	1.51	,,	
14.	1.51	,,	

Arithmetic Mean = $\bar{X}$ = 1.529 sec

Standard deviation = 0.011

TABLE - 6

Sl. No.	Operating time of the relay for transient operation
1.	0.65 sec
2.	0.66 ,,
3.	0.65 ,,
4.	0.66 ,,
5.	0.63 ,,
6.	0.63 ,,
7.	0.63 ,,
8.	0.65 ,,
9.	0.64 (exp)
10.	0.68 ,,

Arithmetic Mean = 0.659

Standard deviation

= σ = 0.0141

Sl. No.	Operating time of the relay for non-transient Operation.
1.	0.70 sec
2.	0.71 ,,
3.	0.70 ,,
4.	0.72 ,,
5.	0.70 ,,
6.	0.71 ,,
7.	0.73 ,,
8.	0.725 ,,
9.	0.71 ,,
10.	0.705 ,,
11.	0.70 ,,
12.	0.70 ,,
13.	0.70 ,, (exp)

Arithmetic Mean = 0.708

Standard deviation

= σ = 0.01008

TABLE - 7

Sl. No.	Operating time of the relay for transient operation.	Sl. No.	Operation time of the relay for non-transient operation.
1.	0.35 sec (exposed)	1.	043
2.	0.36 ,, ,,	2.	0.425 (exposed)
3.	0.35 ,,	3.	0.43 ,,
4.	0.33 ,,	4.	0.435 ,,
5.	0.36 ,,	5.	0.42 ,,
6.	0.36 ,,(exposed)	6.	0.43 ,,
7.	0.38 ,,	7.	0.425 ,,
8.	0.32 ,,	8.	0.44 ,,
9.	0.37 ,,	9.	0.44 ,,
10.	0.32 ,,	10.	0.42 ,,
11.	0.32 ,,		
12.	0.35 ,,		
13.	0.33 ,,		
14.	0.30 ,,		
15.	0.31 ,,		

Arithmetic Mean = $\bar{X}$ = 0.34

Standard deviation

= α = 0.0251

Arithmetic Mean = $\bar{X}$ = 0.4295

Standard deviation

= α = 0.00687

TABLE - 8

TRANSIENT PEAKS IN TERMS OF PERCENT OF PEAK OF STEADY STATE VALUE

Sl. No.	Positive peaks	Sl. No.	Nagative peaks	Sl. No.	Negative peaks
1.	187.5	1.	185.7	24.	166.6
2.	185.5	2.	180.0	25.	165
3.	184.6	3.	177.4	26.	165
4.	183.3	4.	177.4	27.	164.3
5.	183.3	5.	176.9	28.	164.3
6.	180.0	6.	175	29.	164.3
7.	178	7.	175	30.	163.5
8.	178.5	8.	175	31.	162
9.	178.5	9.	175	32.	157
10.	178	10.	175	33.	156.4
11.	175.6	11.	175	34.	155.2
12.	175	12.	175	35.	140
13.	175	13.	174.3	36.	135
14.	174.3	14.	174.3		
15.	174.3	15.	174.3		
16.	174.3	16.	174.3		
17.	174.3	17.	174.3		
18.	172	18.	174.2		
19.	170	19.	174.2		
20.	166.7	20.	174.2		
21.	163	21.	174.2		
22.	158	22.	169.5		
23.	128	23.	166.6		

TABLE - 9

Sl. No.	Transient occurance angle ' λ ' in degress	Operating time of the relay in secs.
1.	25.85	0.83
2.	35.75	0.88
3.	47.45	0.915
4.	36.35	0.90
5.	30.75	0.845
6.	29.45	0.84
7.	32.65	0.87
8.	31.95	0.85

TABLE - 10

Sl. No.	Transient occurance angle ' λ ' in degrees	Operating time of the relay in secs.
1.	30.65	0.66 secs
2.	24.85	0.625
3.	24.85	0.625
4.	24.85	0.63
5.	24.85	0.625
6.	17.25	0.58
7.	24.85	0.63
8.	24.85	0.63
9.	24.85	0.63
10.	24.85	0.625

TABLE - 11

Sl. No.	Transient occurance angle 'λ' in degrees	Operating time of the relay in secs.
1.	24.25	0.87
2.	19.85	0.84
3.	26.85	0.90
4.	24.05	0.86
5.	26.65	0.89
6.	24.05	0.85
7.	25.55	0.88
8.	26.65	0.89
9.	26.65	0.90
10.	30.80	0.92

TABLE - 12

Sl.No.	Transient occurance angle ' λ ' in degrees	Operating time of the relay in secs.
1.	24.2	1.885
2.	34.7	1.895
3.	17.3	1.86
4.	24.2	1.88

TABLE - 13

Sl.No.	Transient occurance angle ' λ ' in dégress	Operating time of the relay in secs.
1.	36.1	1.46
2.	32.7	1.44
3.	19.8	1.41
4.	24.7	1.42

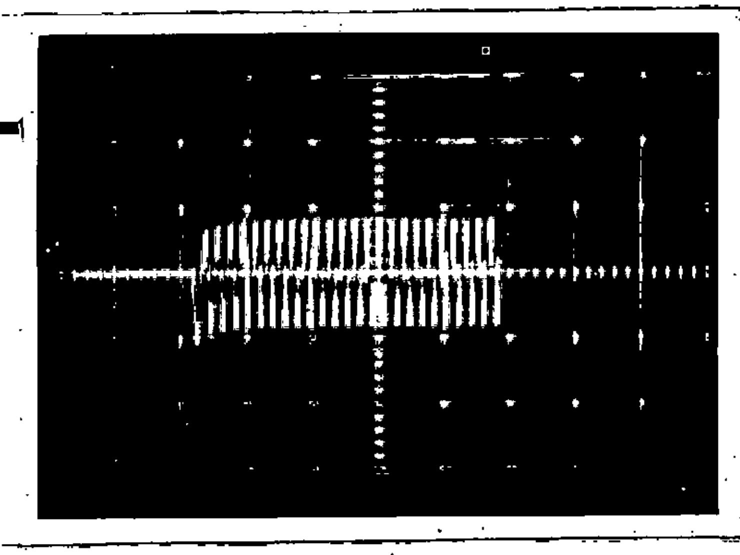
TABLE - 14

Sl.No.	Transient occurance angle' λ 'in degress	Operating time of the relay in secs.
1.	26.1	0.65
2.	30.8	0.665
3.	26.1	0.66
4.	26.1	0.66
5.	20.8	0.63
6.	26.1	0.65
7.	20.8	0.63
8.	26.1	0.65

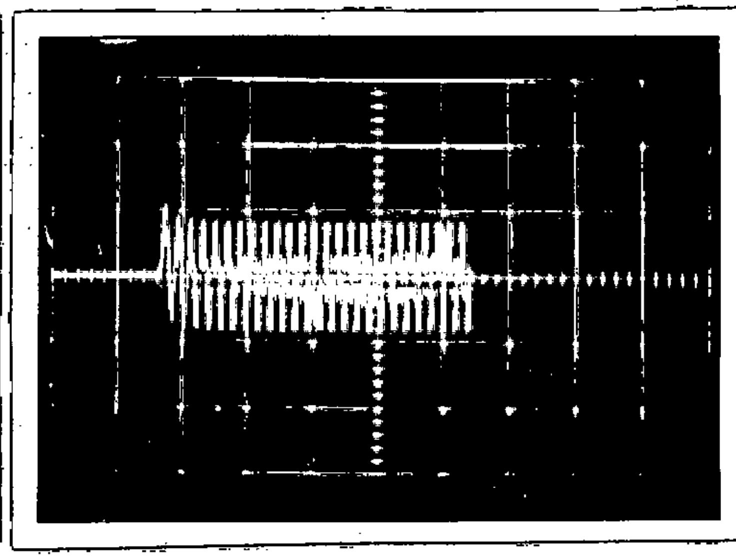
TABLE - 15

Sl.No.	Transient occurance angle ' λ ' in degrees	Operating time of the relay in secs.
1.	32.15	0.35
2.	28.35	0.33
3.	33.65	0.36
4.	45.25	0.38
5.	26.65	0.32
6.	43.25	0.37
7.	26.65	0.32
8.	26.65	0.32
9.	32.15	0.35
10.	29.55	0.33
11.	23.55	0.30
12.	25.85	0.31

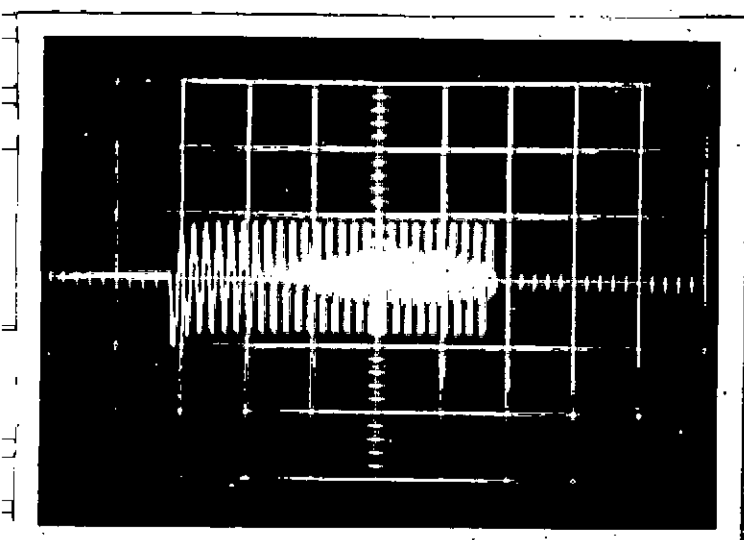
PLATE - I
(NON-TRANSIENT)



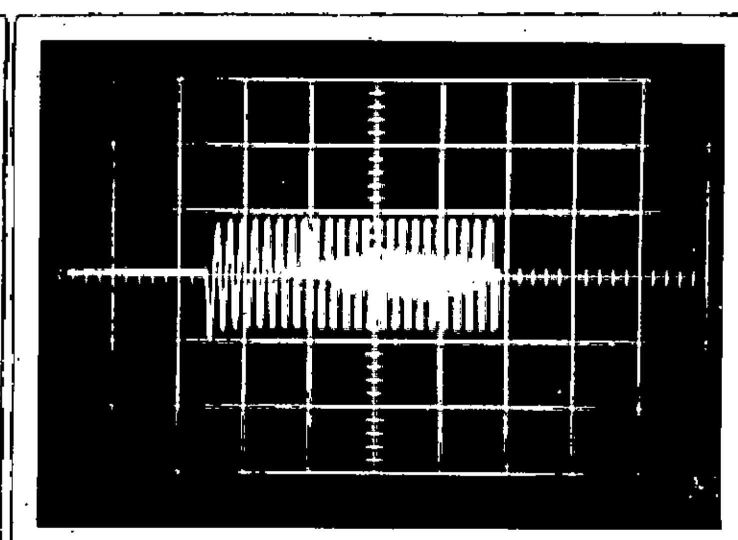
RESISTANCE ≐ 1.902 ohms
INDUCTANCE ≐ 126.6 mH
SPEED ≐ 0.1 sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.935 sec
(2)



RESISTANCE ≐ 1.902 ohms
INDUCTANCE ≐ 126.6 mH
SPEED ≐ 0.1 sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.935 sec
(1)

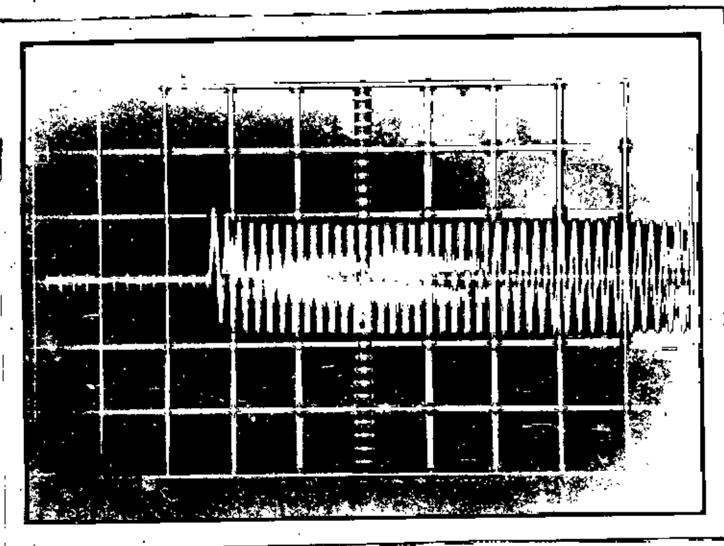


RESISTANCE ≐ 1.902 ohms
INDUCTANCE ≐ 126.6 mH
SPEED ≐ 0.1 sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.93 sec
(4)

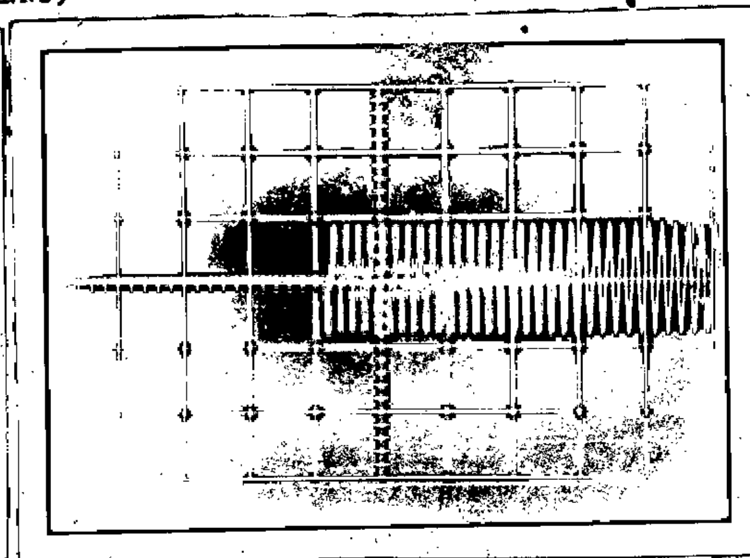


RESISTANCE ≐ 1.902 ohms
INDUCTANCE ≐ 126.6 mH
SPEED ≐ 0.1 sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.93 sec
(3)

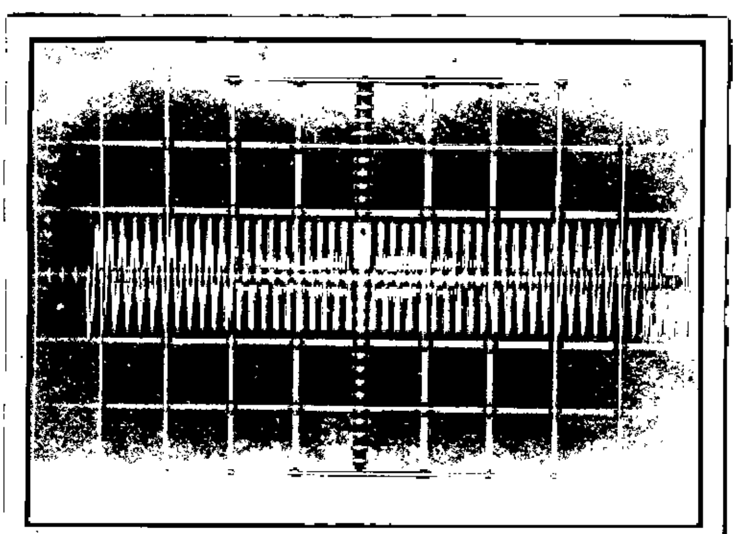
PLATE - I
(NON-TRANSIENT)



RESISTANCE = 1.902 ohms
INDUCTANCE = 126.6 mH
SPEED = 0.1 sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.93 sec
(6)



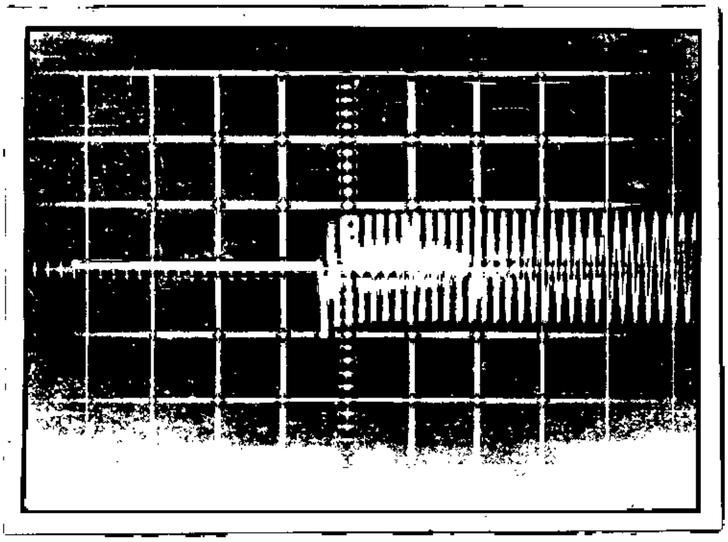
RESISTANCE = 1.902 ohms
INDUCTANCE = 126.6 mH
SPEED = 0.1 sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.94 sec
(5)



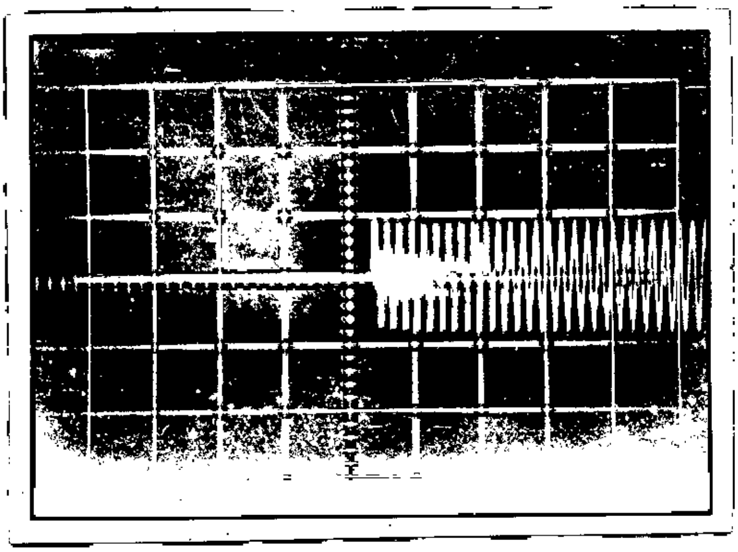
RESISTANCE = 1.902 ohms
INDUCTANCE = 126.6 mH
SPEED = 0.1 sec/cm
SENSETIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.935 sec
(8)

RESISTANCE = 1.902 ohms
INDUCTANCE = 126.6 mH
SPEED = 0.1 sec/cm
SENSETIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.92 sec
(7)

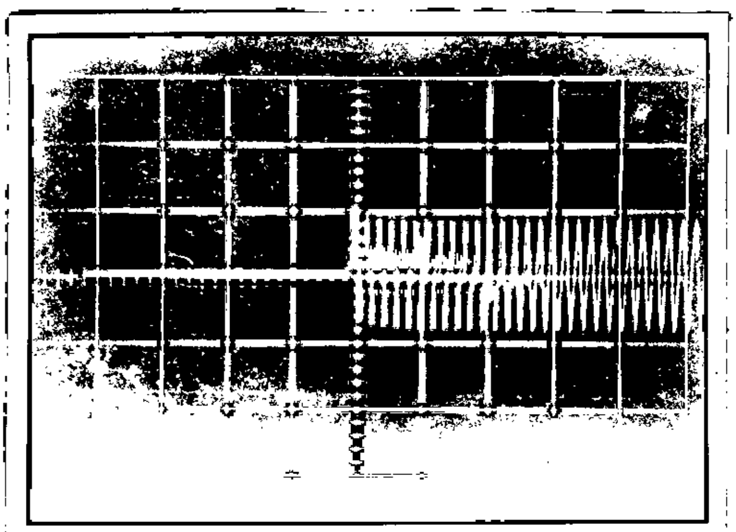
PLATE-I
(NON-TRANSIENT)



RESISTANCE = 1.902 ohms
INDUCTANCE = 126.6 mH
SPEED = 0.1 sec/cm
SENSETIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.93 sec
(10)

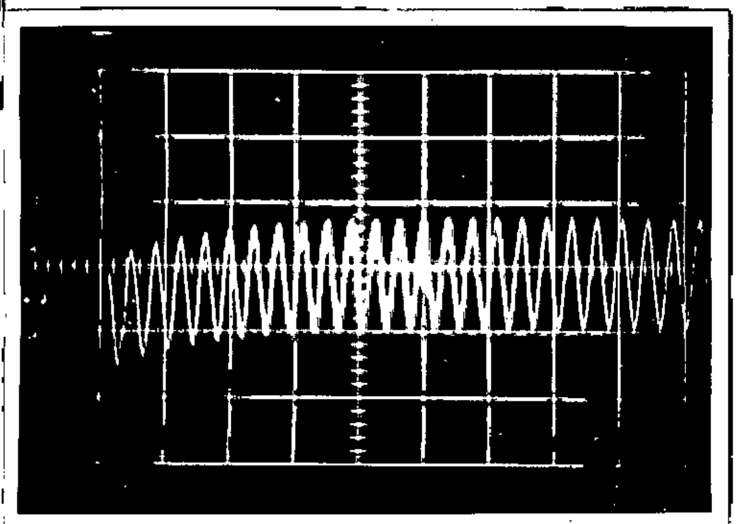


RESISTANCE = 1.902 ohms
INDUCTANCE = 126.6 mH
SPEED = 0.1 sec/c,
SENSETIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.94 sec
(9)



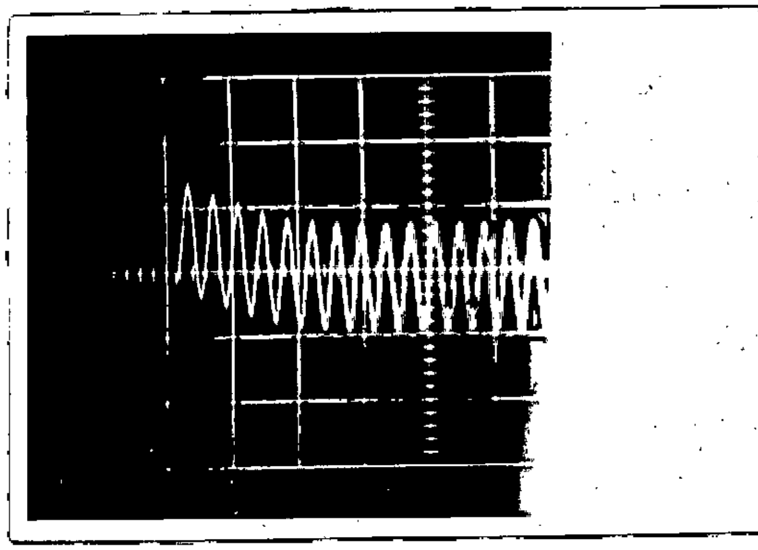
RESISTANCE = 1.902 ohms
INDUCTANCE = 126.6 mH
SPEED = 0.1 sec/cm
SENSETIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.935 sec
(11)

PLATE - 1
(TRANSIENT)



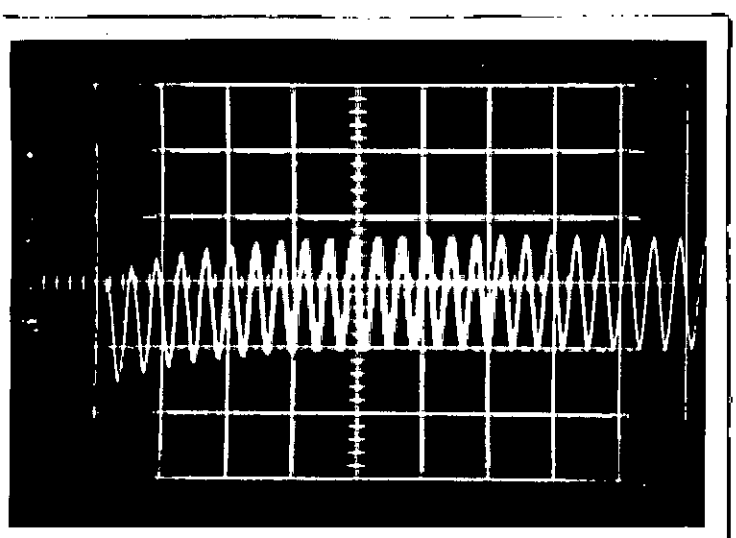
RESISTANCE = 1.902 ohms
INDUCTANCE = 126.6 mH
SPEED = 60 m sec/cm
SENSETIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.88 sec
PEAK =-156.4%

(2)



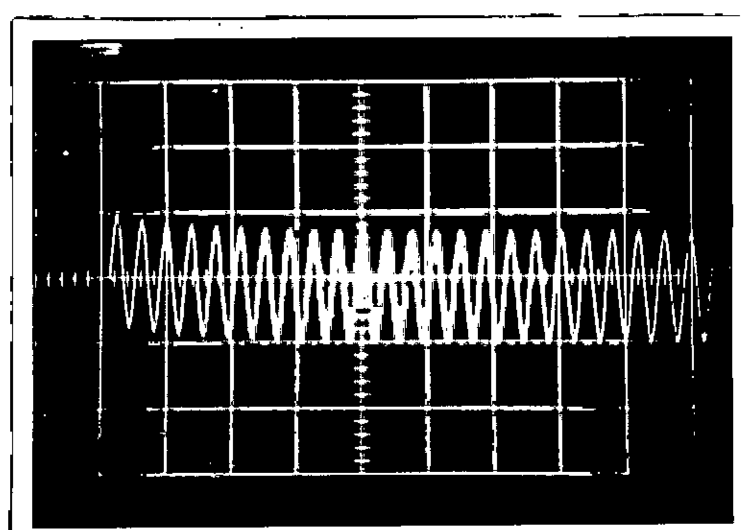
RESISTANCE = 1.902 ohms
INDUCTANCE = 126.6 mH
SPEED = 60 m sec/cm
SENSETIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.83 sec
PEAK = +175.6%

(1)



RESISTANCE = 1.902 ohms
INDUCTANCE = 126.6 mH
SPEED = 60 m sec/cm
SENSETIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.90 sec
PEAK = 155.2%

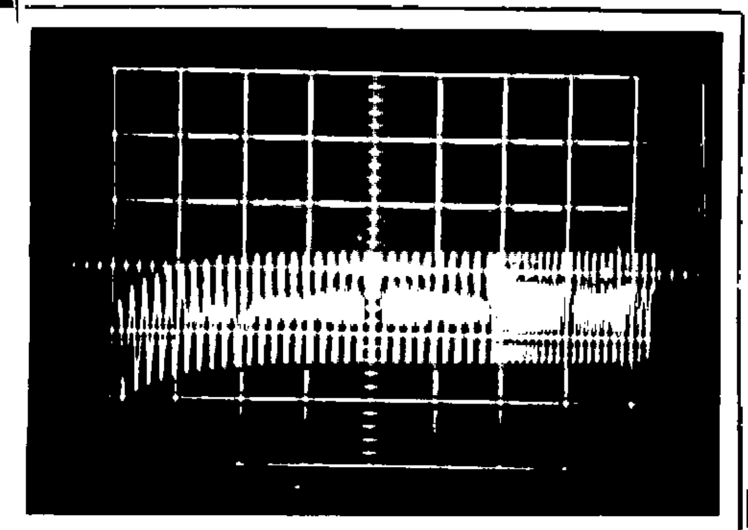
(4)



RESISTANCE = 1.902 ohms
INDUCTANCE = 126.6 mH
SPEED = 60 m sec/cm
SENSETIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.915 sec
PEAK = + 128.1%

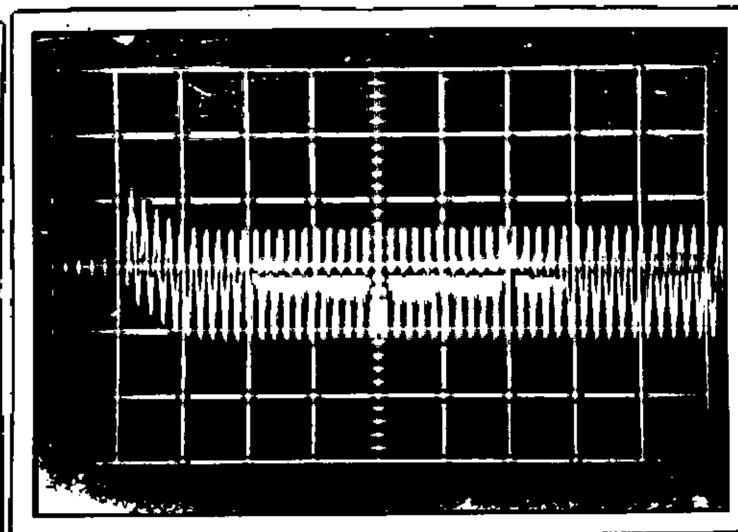
(3)

PLATE - I
(TRANSIENT)



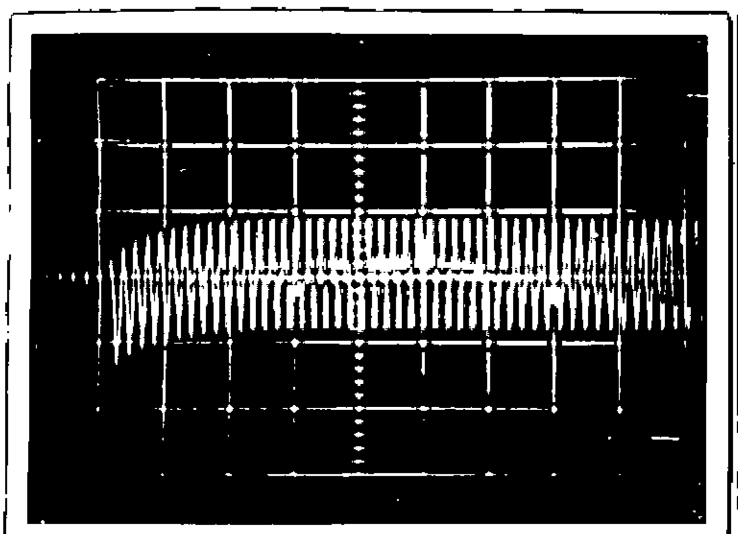
RESISTANCE = 1.902 ohms
INDUCTANCE = 126.6 mH
SPEED = 0.1 ~~V/cm~~ sec/cm
SENSETIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.84 sec
PEAK = -169.3%

(6)



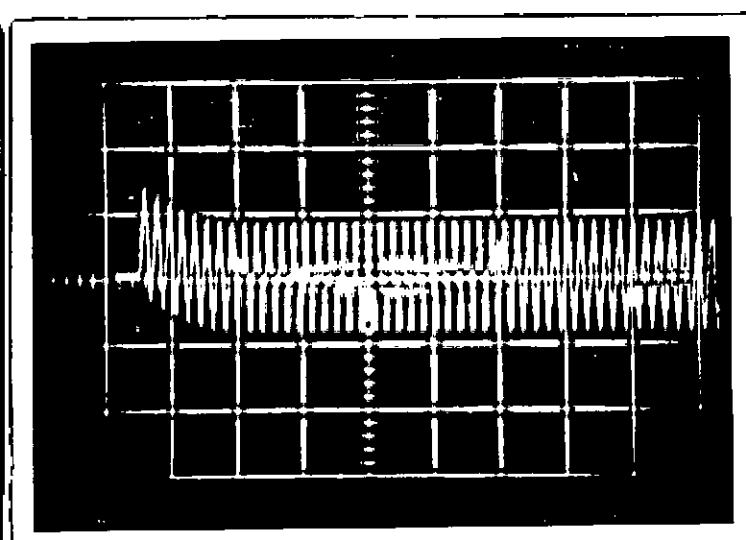
RESISTANCE = 1.902 ohms
INDUCTANCE = 126.6mH
SPEED = 0.1 ~~V/cm~~ sec/cm
SENSETIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.845 sec
PEAK = + 166.7%

(5)



RESISTANCE = 1.902 ohms
INDUCTANCE = 126.6 mH
SPEED = 0.1 sec/cm
SENSETIVITY = 0.05 V/cm
RELAY OPERATING
TIME = ~~164.4%~~ 0.85 sec
PEAK = -164.4%

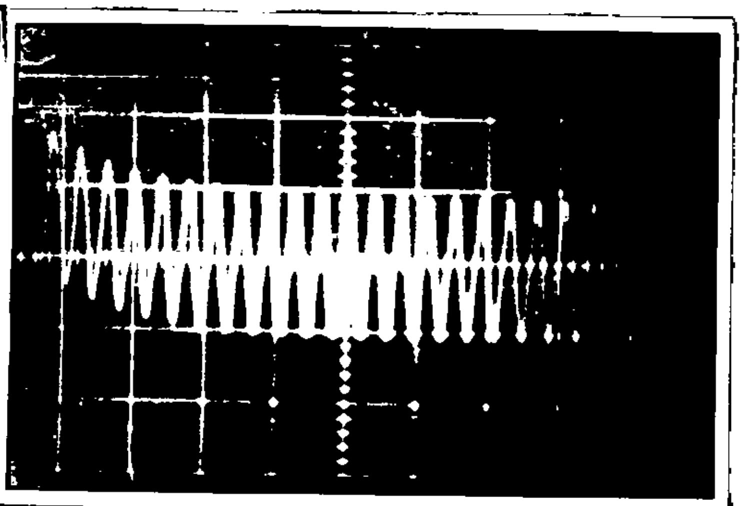
(8)



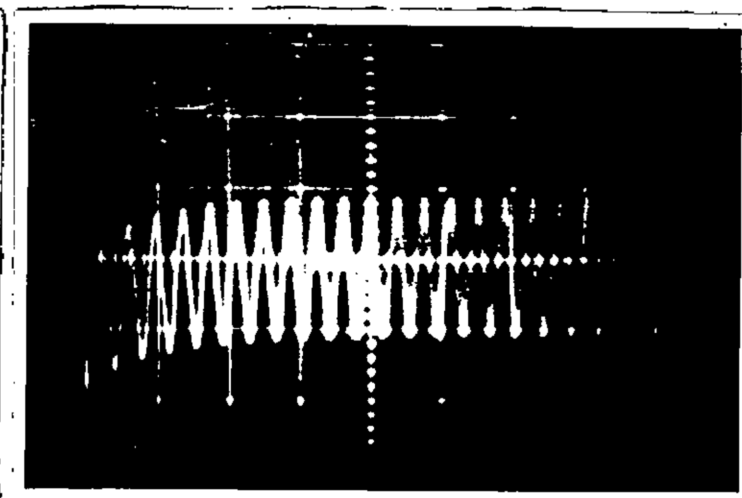
RESISTANCE = 1.902 ohms
INDUCTANCE = 126.6 mH
SPEED ~~axx~~ 0.1 sec/cm
SENSETIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.87 sec
PEAK = 163.0%

(7)

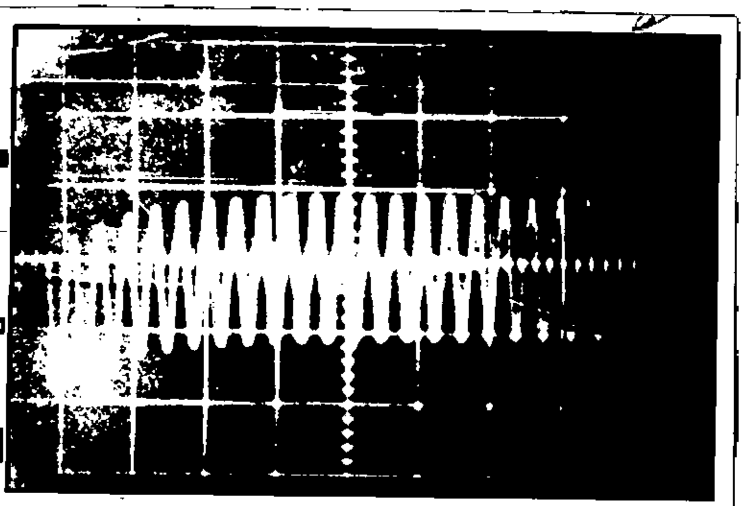
PLATE 2A
(TRANSIENT)



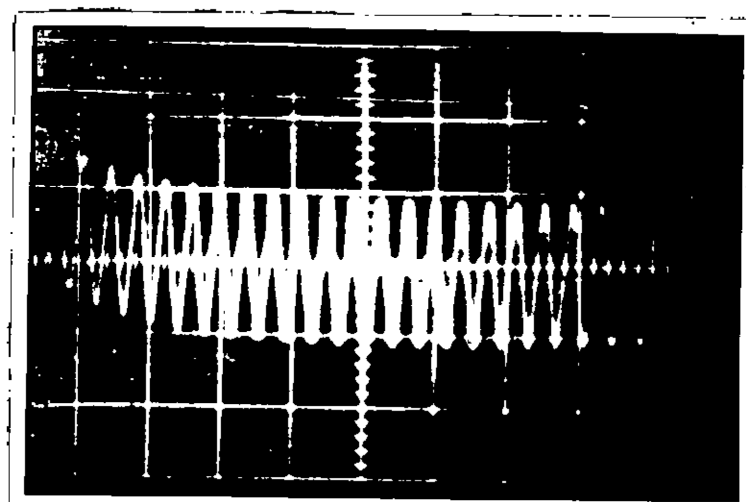
RESISTANCE = 1.719 ohms
INDUCTANCE = 100.34 mH
SPEED = 50 m sec/cm
SENSETIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.625 sec
PEAK = +174.3%
(2)



RESISTANCE = 1.719 ohms
INDUCTANCE = 100.34 mH
SPEED = 50 m sec/cm
SENSETIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.66 sec
PEAK = -163.5%
(1)

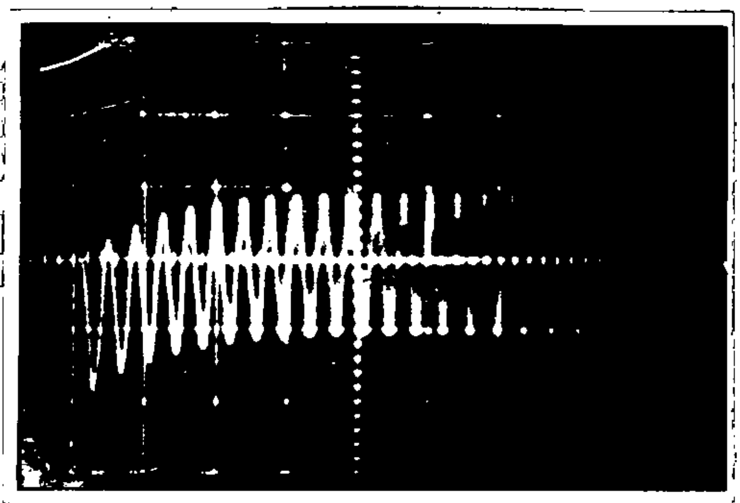


RESISTANCE = 1.719 ohms
INDUCTANCE = 100.34 mH
SPEED = 50 m sec/cm
SENSETIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.63 sec
PEAK = -174.3%
(4)

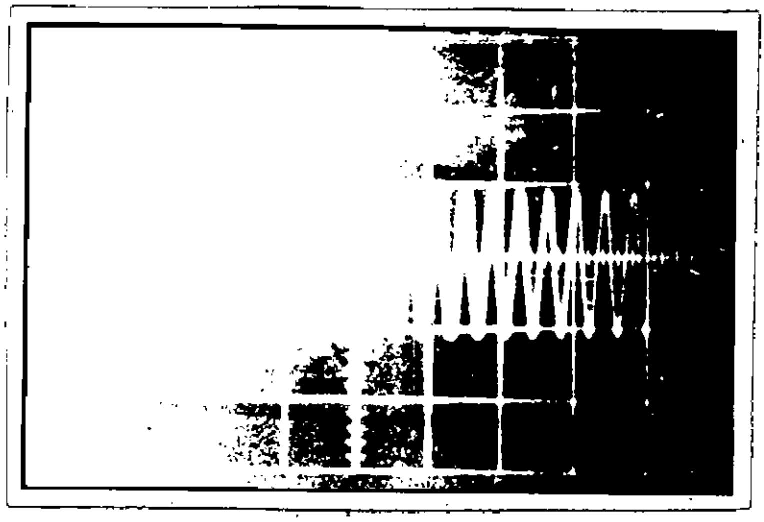


RESISTANCE = 1.719 ohms
INDUCTANCE = 100.34 mH
SPEED = 50 m sec/cm
SENSETIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.625 sec
PEAK = +174.3%
(3)

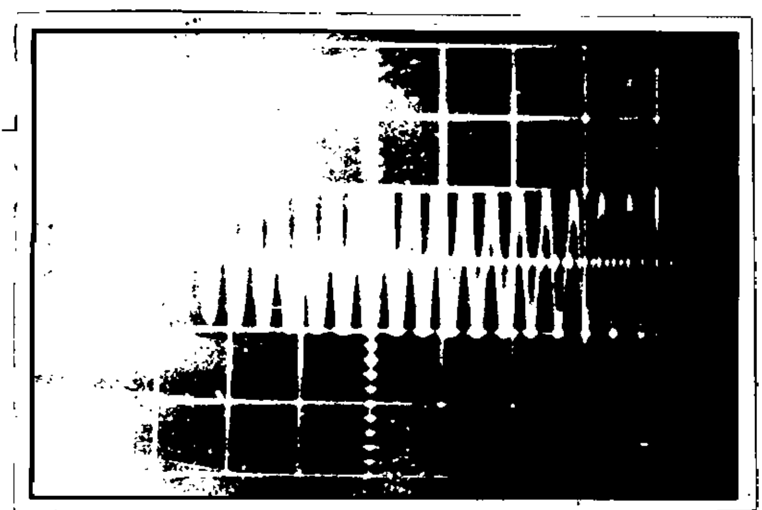
PLATE - 2A
(TRANSIENT)



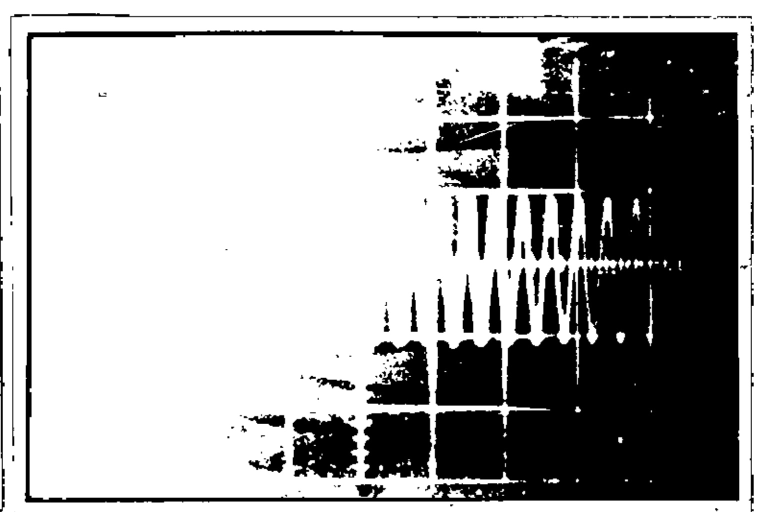
RESISTANCE = 1.719 ohms
INDUCTANCE = 100.34 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.58 sec
PEAK = -185.7%
(6)



RESISTANCE = 1.719 ohms
INDUCTANCE = 100.34 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.625 sec.
PEAK = -174.3%
(5)

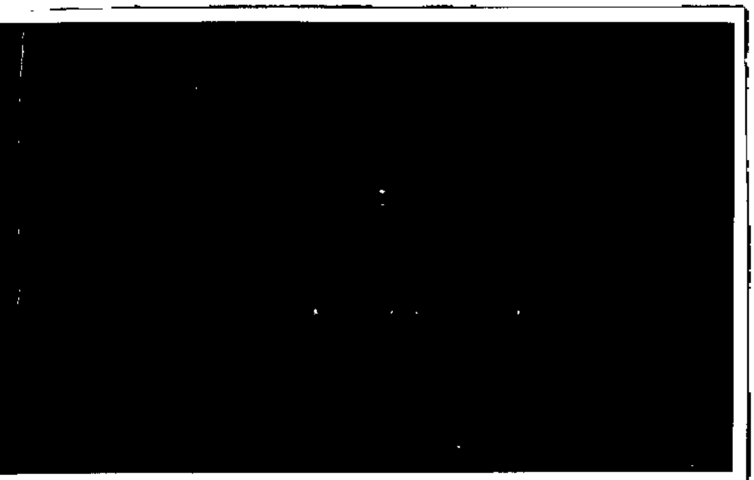


RESISTANCE = 1.719 ohms
INDUCTANCE = 100.34 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.63 sec
PEAK = + 174.3%
(8)



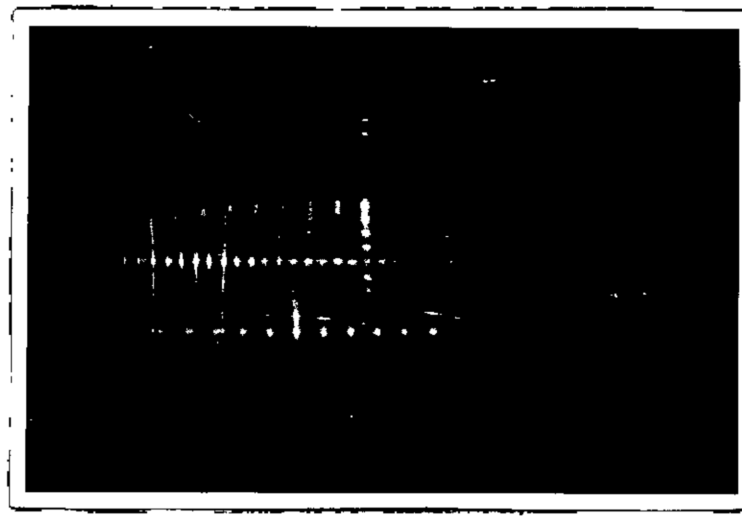
RESISTANCE = 1.719 ohms
INDUCTANCE = 100.34 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.63 sec
PEAK = +174.3%
(7)

PLATE -2A
(Transient)



RESISTANCE = 1.719 ohms
INDUCTANCE = 100.34 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.625 sec
PEAK = -174.3%

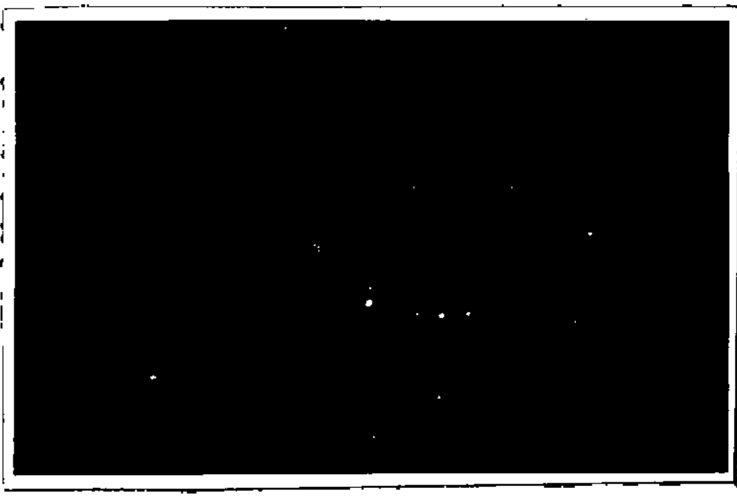
(10)



RESISTANCE = 1.719 ohms
INDUCTANCE = 100.34 mH
SPEED ≠ 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.63 sec
PEAK = -174.3%

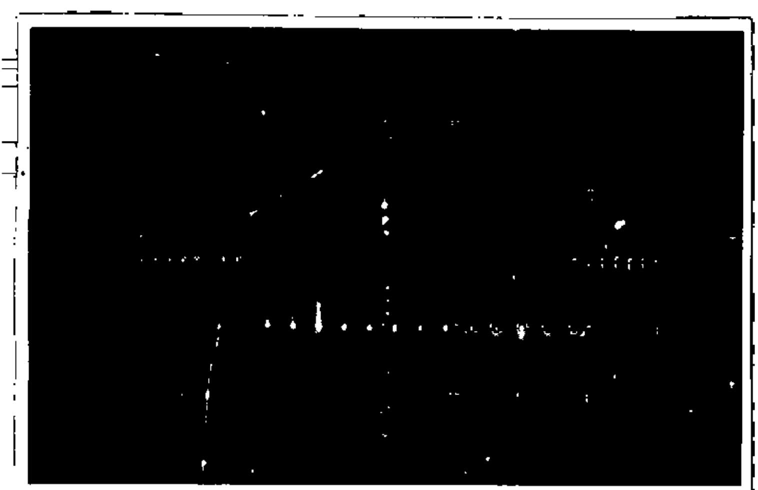
(9)

PLATE 2A
(NON-TRANSIENT)



RESISTANCE ≐ 1.719 ohms
INDUCTANCE ≐ 100.34 mH
SPEED ≐ 50 m sec/cm
SENSETIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.68 sec
(2)

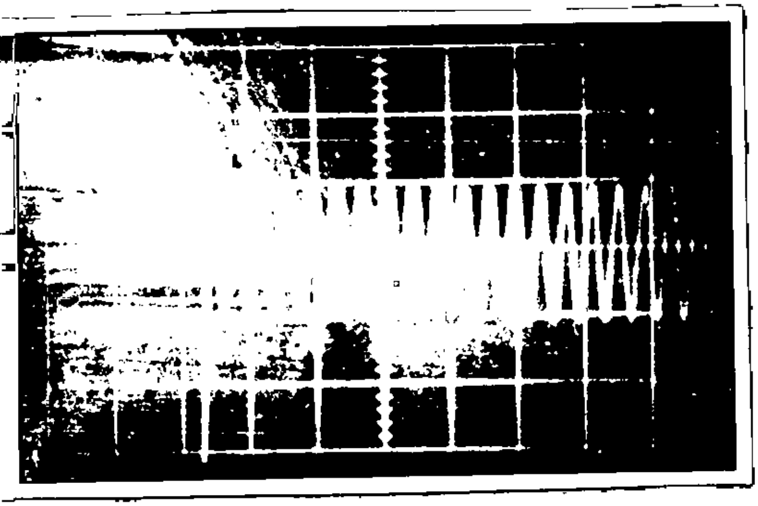
RESISTANCE = 1.719 ohms
INDUCTANCE = 100.34 mH
SPEED = 50 m sec/cm
SENSETIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.69 sec
(1)



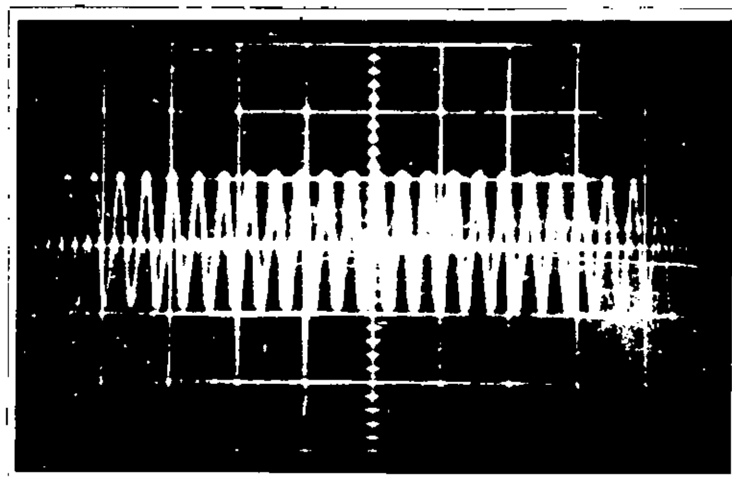
RESISBANCE ≐ 1.719 ohms
INDUCTANCE ≐ 100.34 mH
SPEED ≐ 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.68 sec
(4)

RESISTANCE = 1.719 ohms
INDUCTANCE ≐ 100.34 mH
SPEED = 50 m sec/cm
SENSITIVITY =0.05 V/cm
RELAY OPERATING
TIME = 0.69 sec.
(3)

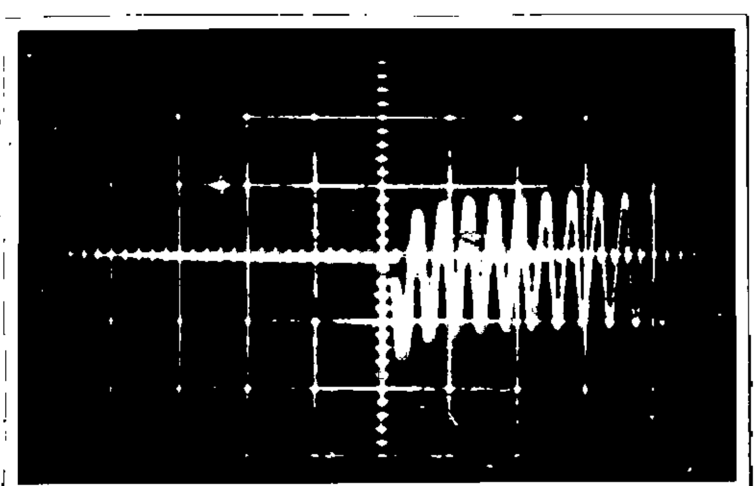
PLATE - 2A
(NON-TRANSIENT)



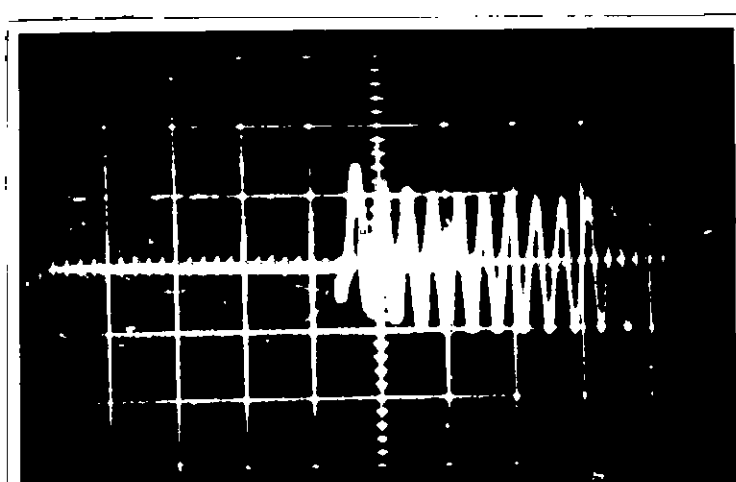
RESISTANCE ≐ 1.719 ohms
INDUCTANCE ≐ 100.34 mH
SPEED ≐ 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.68 sec
(6)



RESISTANCE ≐ 1.719 ohms
INDUCTANCE = 100.34 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.69 sec
(5)

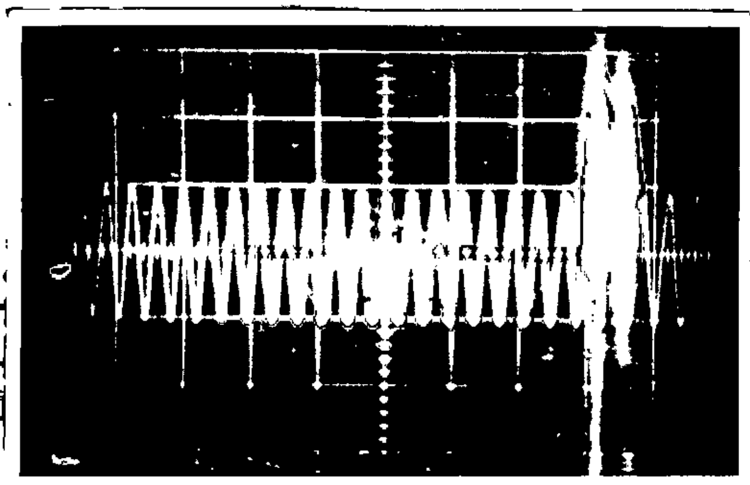


RESISTANCE ≐ 1.719 ohms
INDUCTANCE ≐ 100.34 mH
SPEED ≐ 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.67 sec
(8)

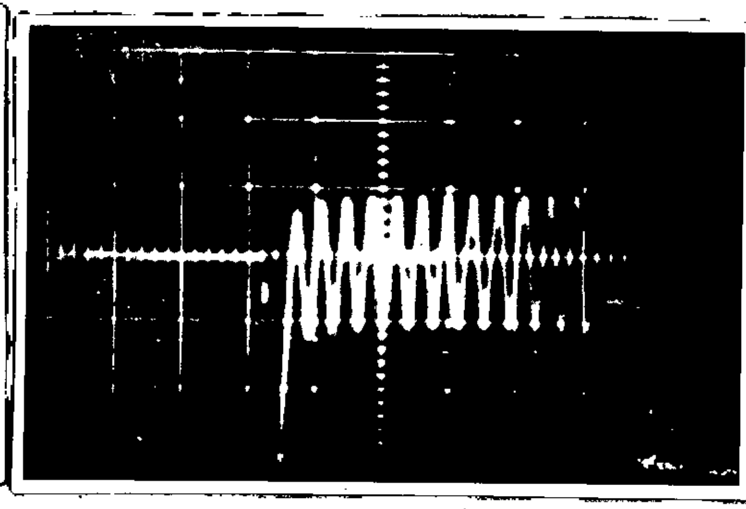


RESISTANCE = 1.719 ohms
INDUCTANCE = 100.34 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.67 sec
(7)

PLATE 2A
(NON-TRANSIENT)

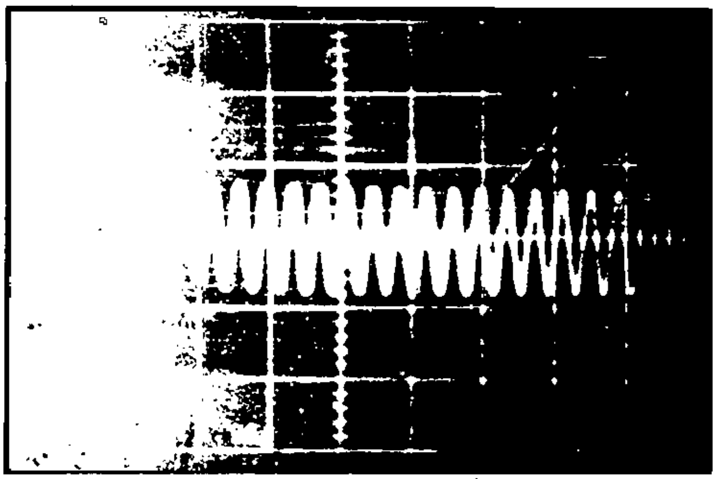


~~RESISTANCE~~xxxx
SPEED = 50 m sec/cm
SENSITIVITY= 0.05 V/cm
RELAY OPERATING
TIME = 0.69 sec
(10)



SPEED = 50 m sec/cm
SENSITIVITY= 0.05 V/cm
RELAY OPERATING
TIME = 0.68 sec
(9)

PLATE 2B
(TRANSIENT)



RESISTANCE ≐ 1.902 ohms
INDUCTANCE ≐ 126.6 mH
SPEED ≐ 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME ≐ 0.84 sec
PEAK = +184.6

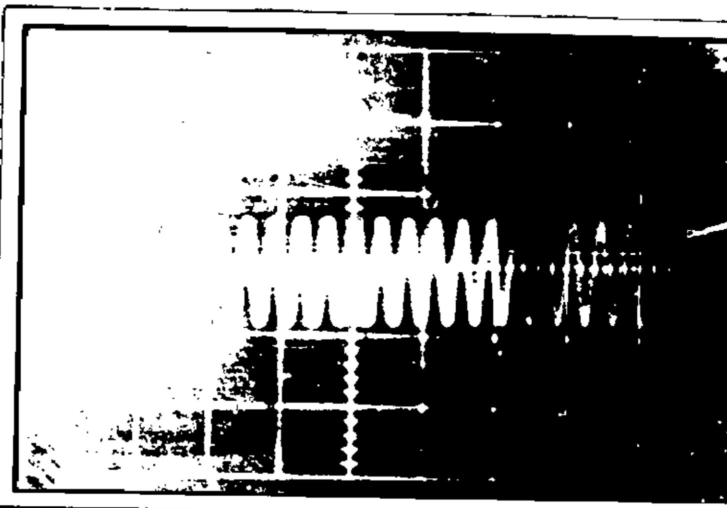
(2)

RESISTANCE ≐ 1.902 ohms
INDUCTANCE ≐ 126.6 mH
SPEED ≐ 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME ≐ 0.87 sec
PEAK = +178.5

(1)

RESISTANCE ≐ 1.902 ohms
INDUCTANCE ≐ 126.6 mH
SPEED ≐ 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.86 sec
PEAK = +178.5%

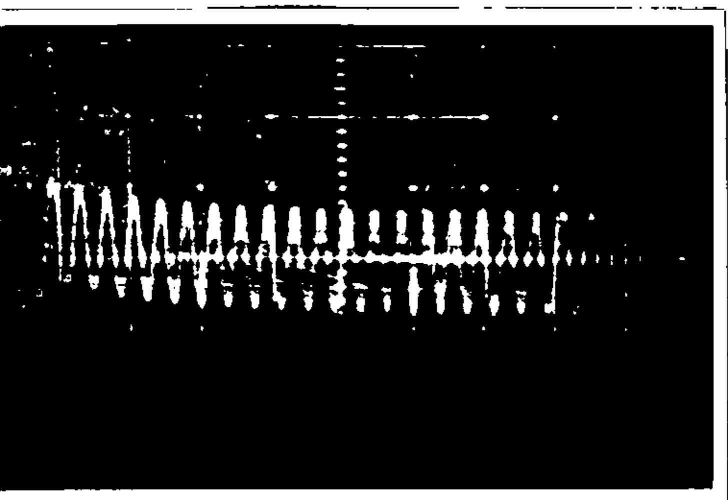
(4)



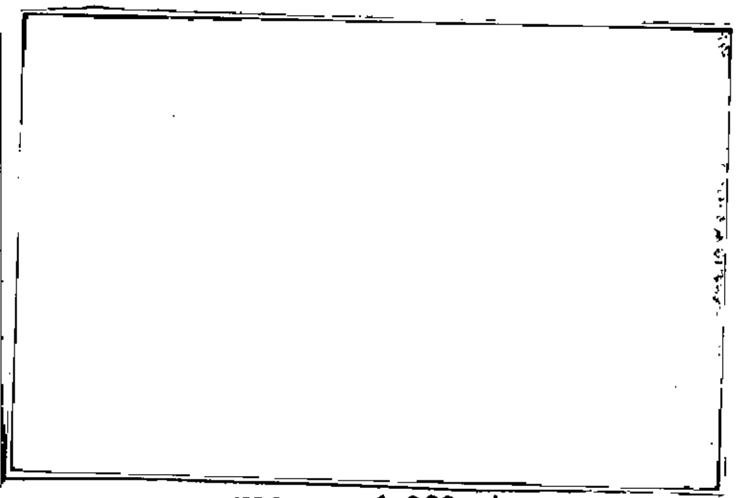
RESISTANCE ≐ 1.902 ohms
INDUCTANCE ≐ 126.6 mH
SPEED ≐ 50 m sec/cm
SENSITIVITY = 0.05 V/cm.
RELAY OPERATING
TIME ≐ 0.90 sec
PEAK = -174.0%

(3)

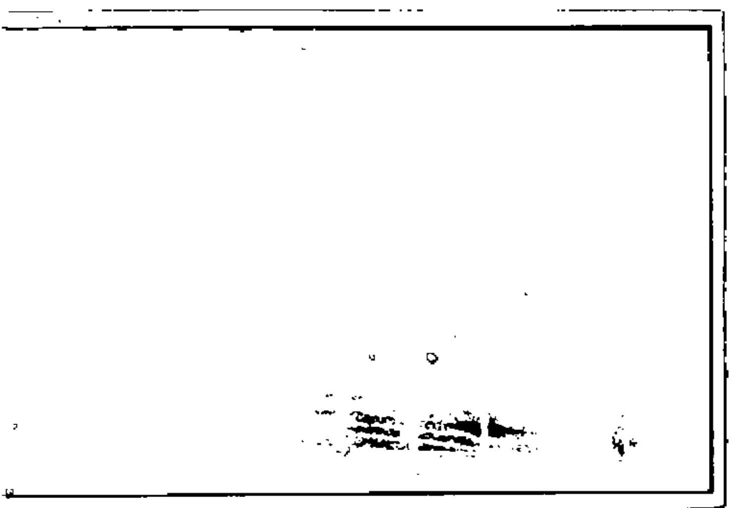
PLATE 2B
(TRANSIENT)



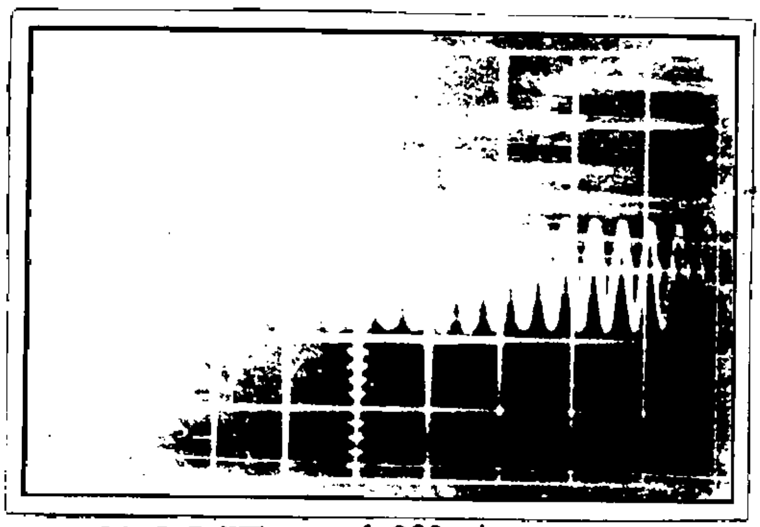
RESISTANCE = 1.902 ohms
INDUCTANCE = 126.6 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.85 sec
PEAK = +178.5%
(6)



RESISTANCE = 1.902 ohms
INDUCTANCE = 126.6 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.89 sec
PEAK = -174.2%
(5)

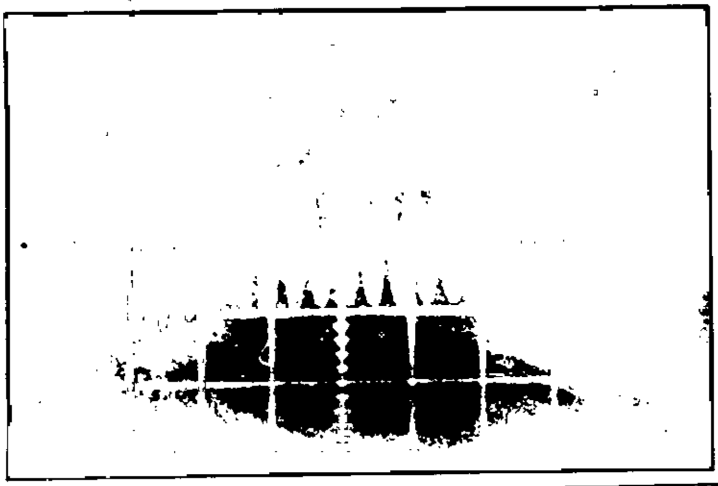


RESISTANCE = 1.902 ohms
INDUCTANCE = 126.6 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.89 sec
PEAK = -174.2%
(8)

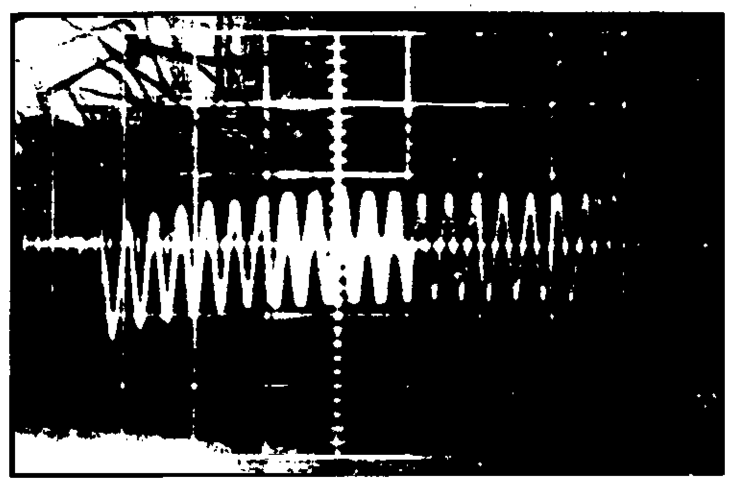


RESISTANCE = 1.902 ohms
INDUCTANCE = 126.6 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.88 sec
PEAK = -176.9%
(7)

PLATE 2B
(TRANSIENT)

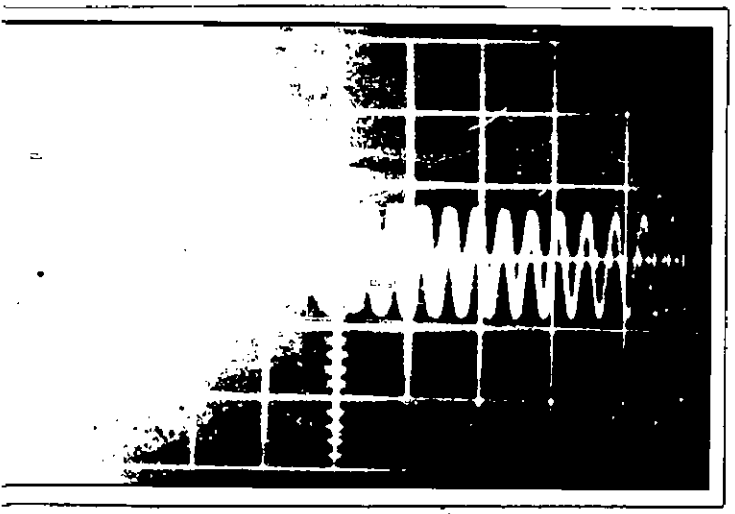


RESISTANCE = 1.902 ohms
INDUCTANCE = 126.6 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.92 sec
PEAK = -166.6%
(10)

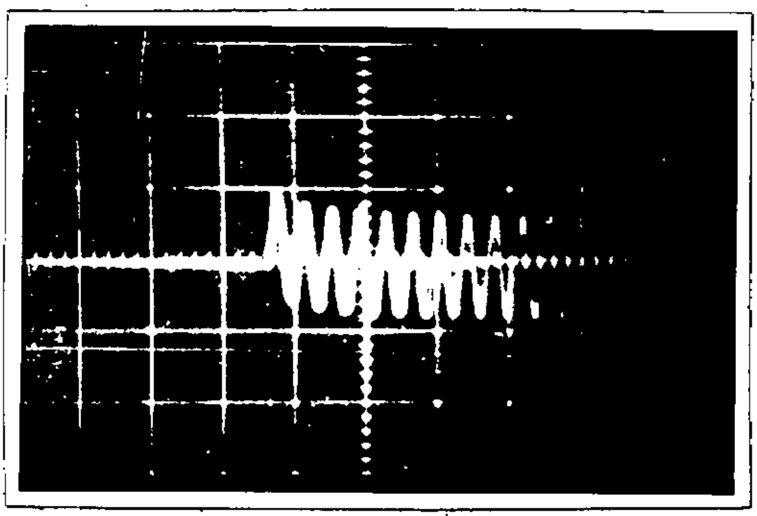


RESISTANCE = 1.902 ohms
INDUCTANCE = 126.6 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.90 sec
PEAK = -174.2%
(9)

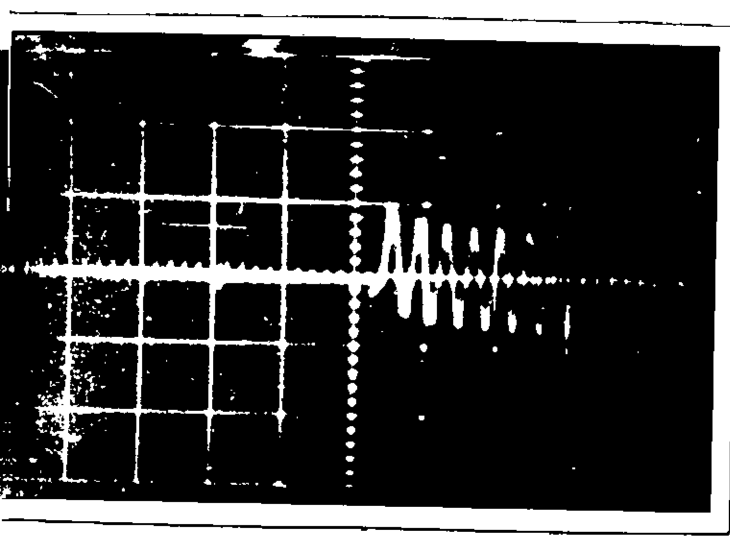
PLATE 2B
(NON-TRANSIENT)



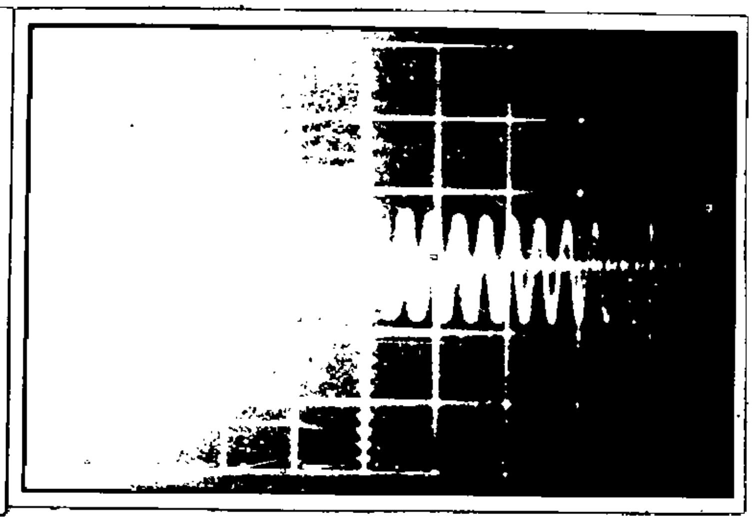
RESISTANCE ≐ 1.902 ohms
INDUCTANCE = 126.6 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATION
TIME = 1.06 sec
(2)



RESISTANCE ≐ 1.902 ohms
INDUCTANCE ≐ 126.6 mH
SPEED ≐ 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATION
TIME = 1.07 sec
(1)

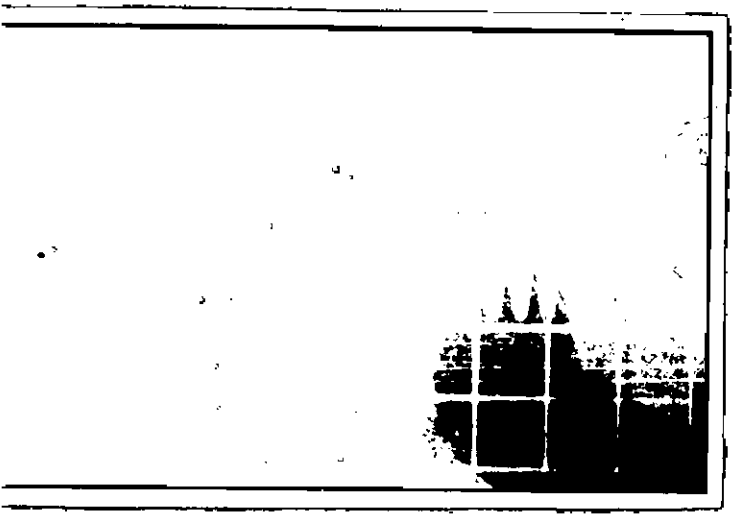


RESISTANCE ≐ 1.902 ohms
INDUCTANCE ≐ 126.6 mH
SPEED ≐ 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.07 sec
(4)

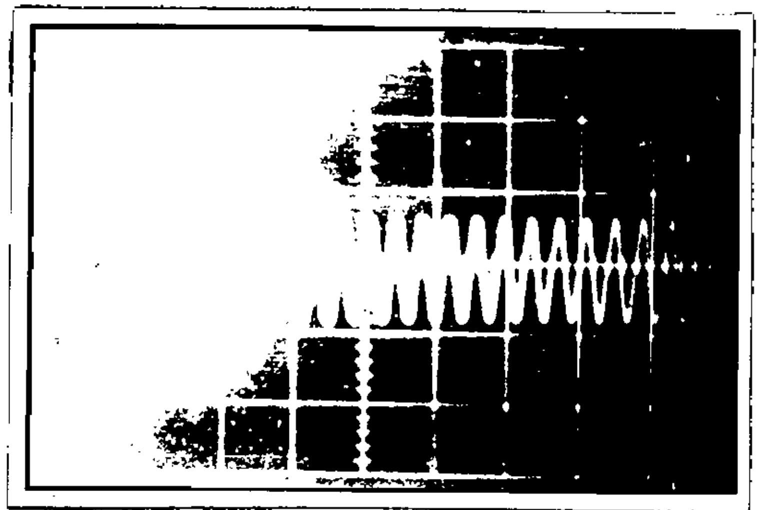


RESISTANCE = 1.902 ohms
INDUCTANCE ≐ 126.6 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.06 sec
(3)

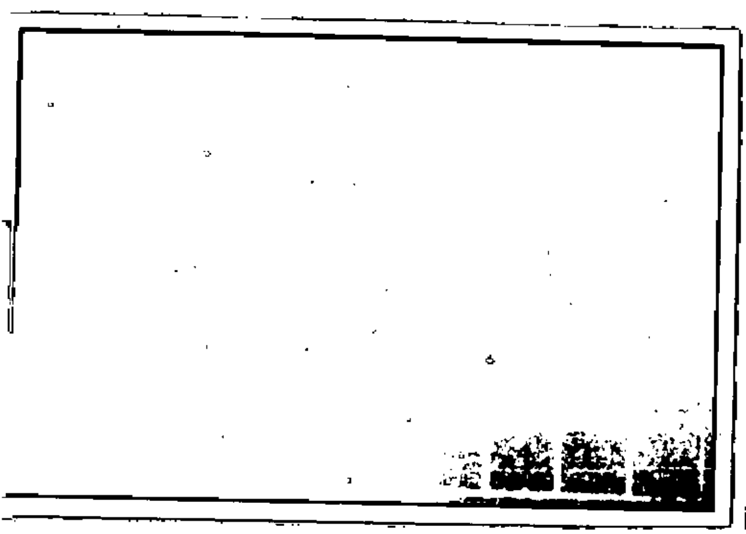
PLATE 2B
(NON-TRANSIENT)



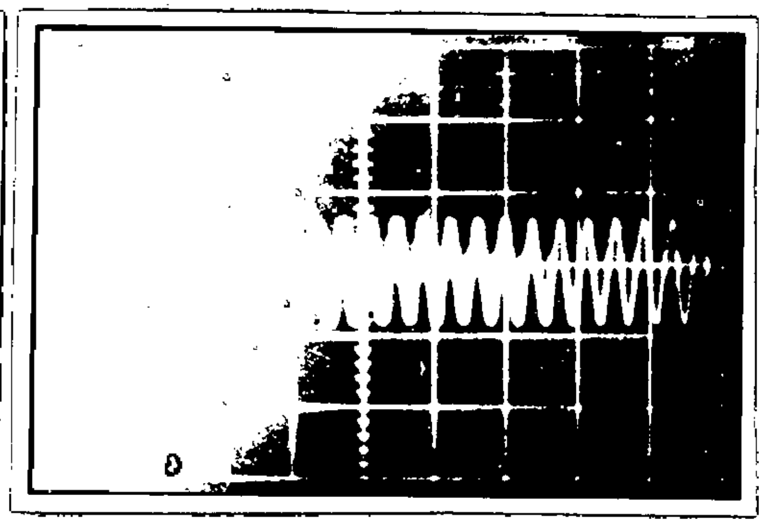
RESISTANCE = 1.902 ohms
INDUCTANCE = 126.6 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.07 sec
(6)



RESISTANCE = 1.902 ohms
INDUCTANCE = 126.6 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.08 sec
(5)

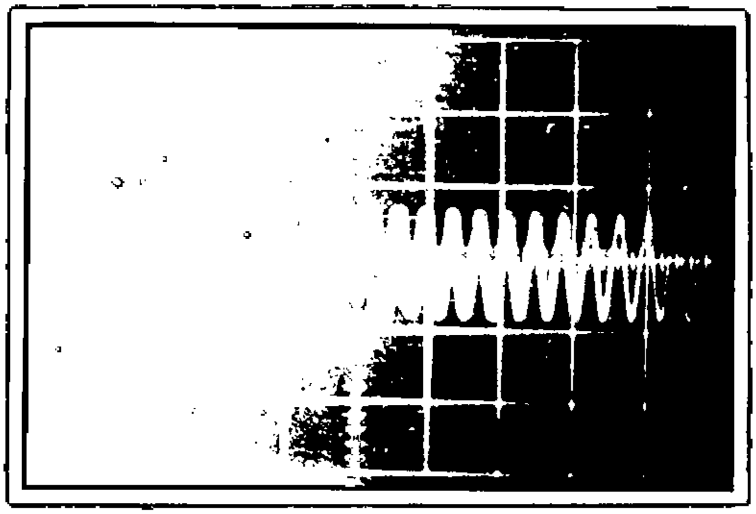


RESISTANCE = 1.902 ohms
INDUCTANCE = 126.6 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.08 sec
(8)



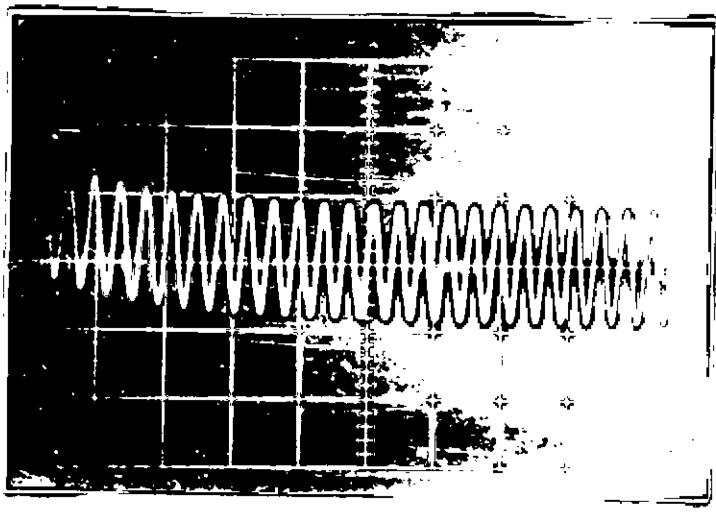
RESISTANCE = 1.902 ohms
INDUCTANCE = 126.6 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.08 sec
(7)

PLATE 2B
(NON-TRANSIENT)



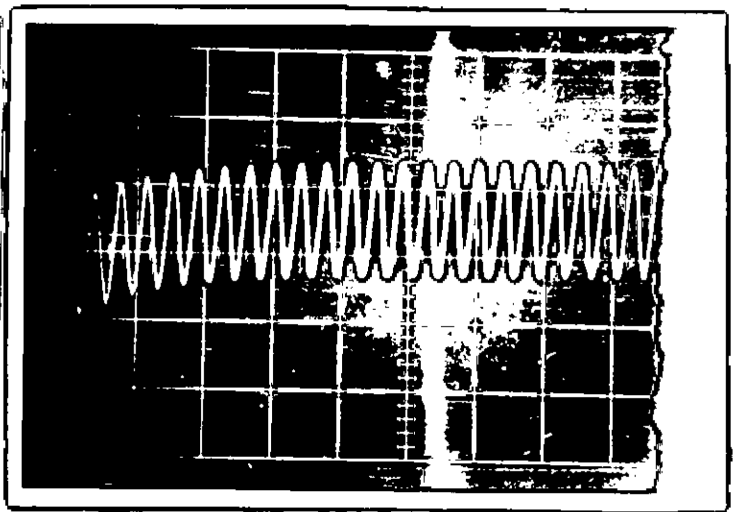
RESISTANCE = 1.902 ohms
INDUCTANCE = 126.6 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.07 sec.
(9)

PLATE 3A
(TRANSIENT)



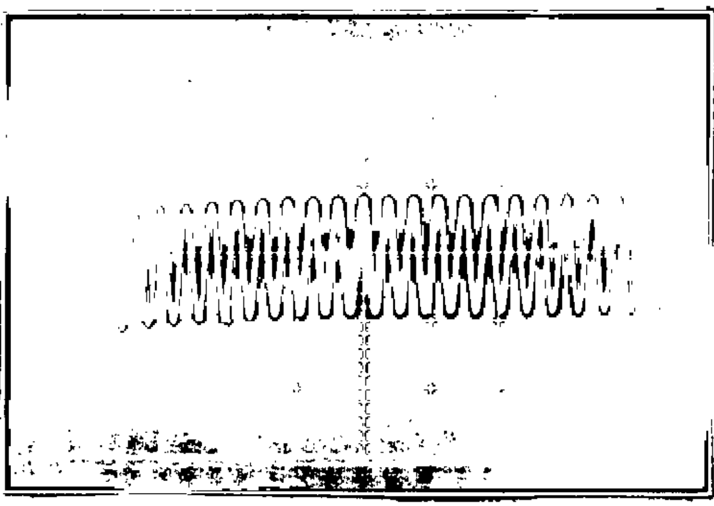
RESISTANCE = 1.719 ohms
INDUCTANCE = 100.34 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.895 sec
PEAK = +158%

(2)

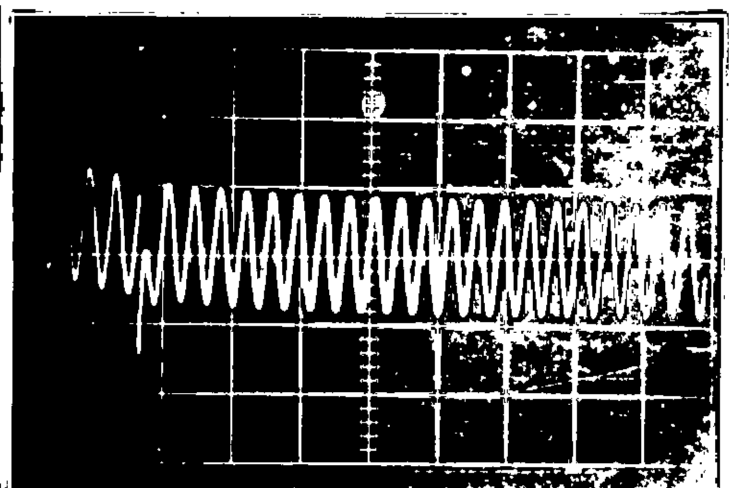


RESISTANCE = 1.719 ohms
INDUCTANCE = 100.34 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.885 sec
PEAK = -177.7%

(1)

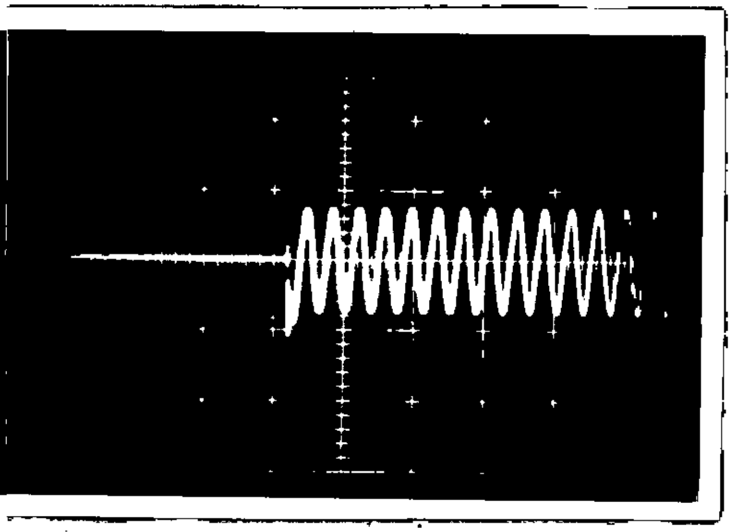


RESISTANCE = 1.719 ohms
INDUCTANCE = 100.34 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.88 sec
PEAK = -177.7%

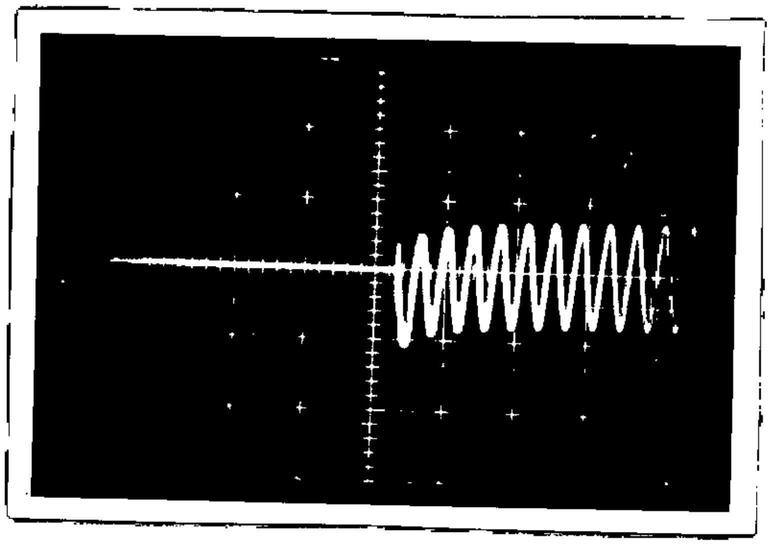


RESISTANCE = 1.719 ohms
INDUCTANCE = 100.34 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.86 sec
PEAK = +187.5%

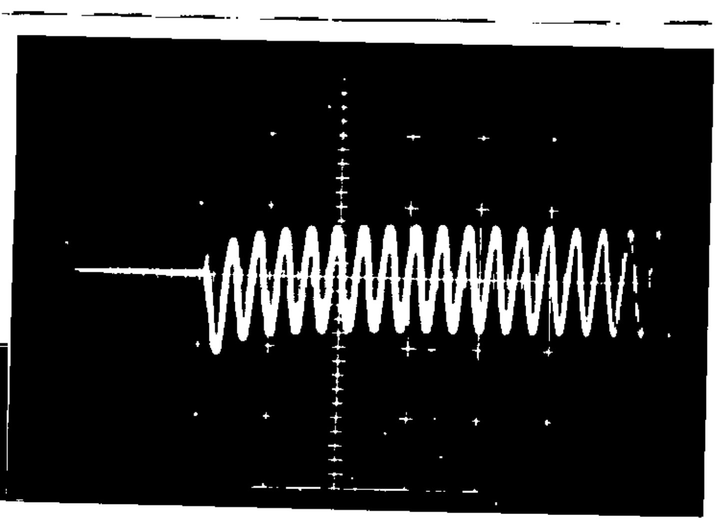
PLATE 3A
(NON-TRANSIENT)



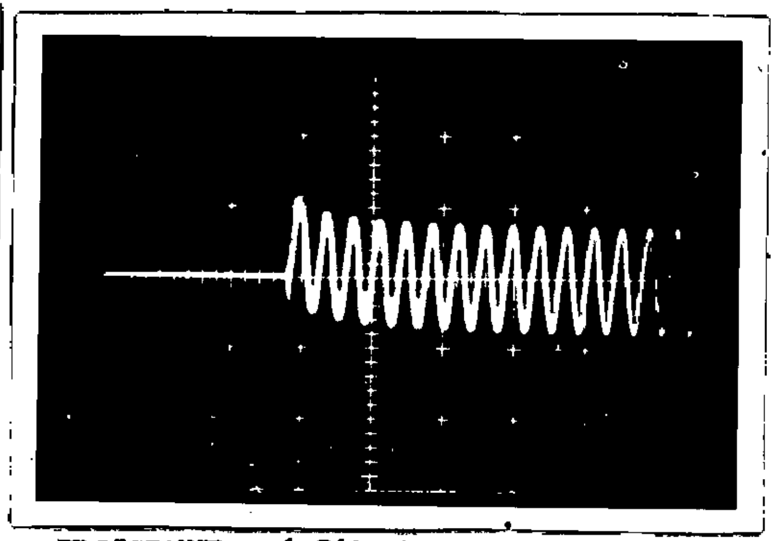
RESISTANCE = 1.719 ohms
INDUCTANCE = 100.34 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.98 sec
(2)



RESISTANCE = 1.719 ohms
INDUCTANCE = 100.34 mH
SPEED = 50 m sec/cm
SENSITIVITY= 0.05 V/cm
RELAY OPERATING
TIME = 1.97 sec
(1)

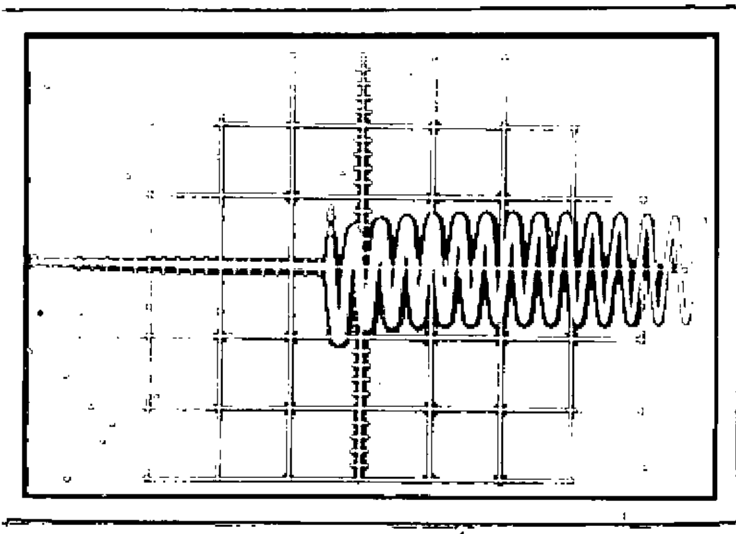


RESISTANCE = 1.719 ohms
INDUCTANCE = 100.34 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.97 sec
(4)

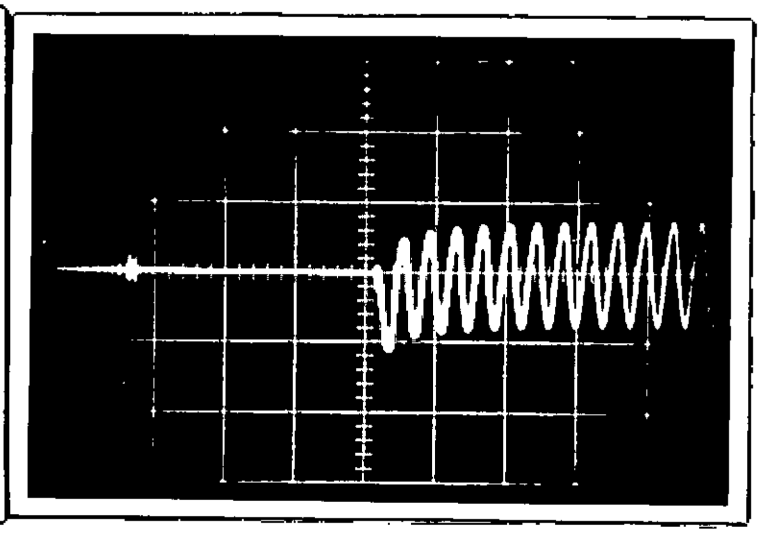


RESISTANCE = 1.719 ohms
INDUCTANCE = 100.34 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.96 sec.
(3)

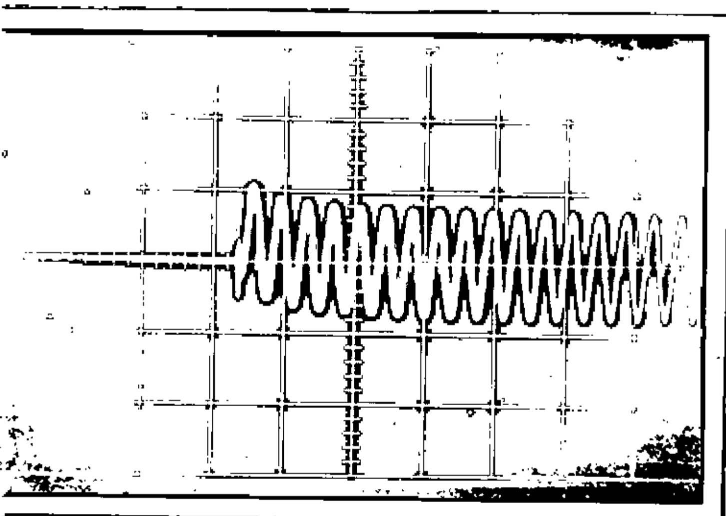
PLATE 3A
(NON-TRANSIENT)



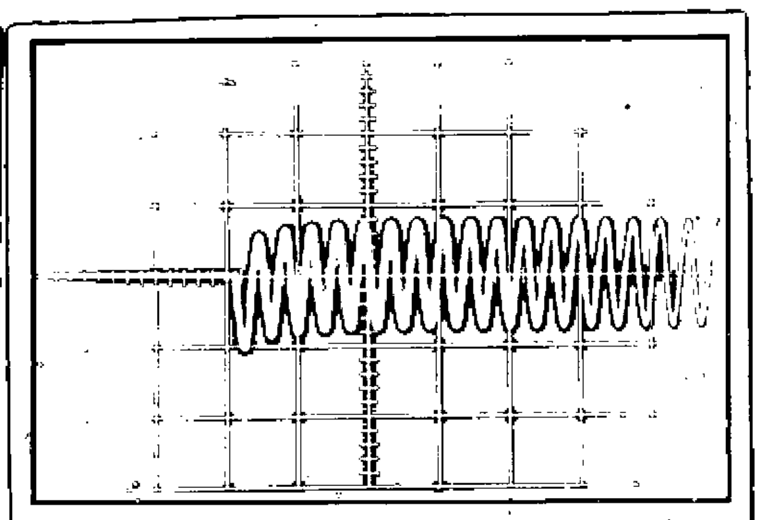
RESISTANCE = 1.719 ohms
INDUCTANCE = 100.34 mH
SPEED ≐ 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.98 sec
(6)



RESISTANCE ≐ 1.719 ohms
INDUCTANCE ≐ 100.34 mH
SPEED ≐ 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.98 sec
(5)

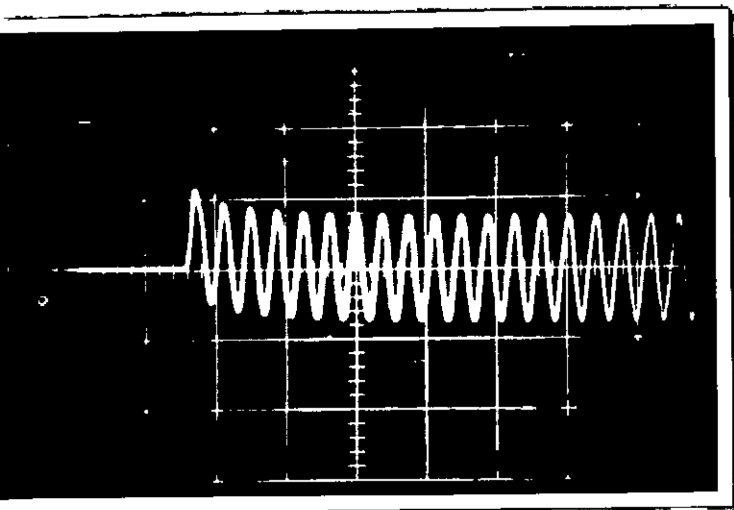


RESISTANCE = 1.719 ohms
INDUCTACE = 100.34 mH
SPEED ≐ 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.97 sec
(8)

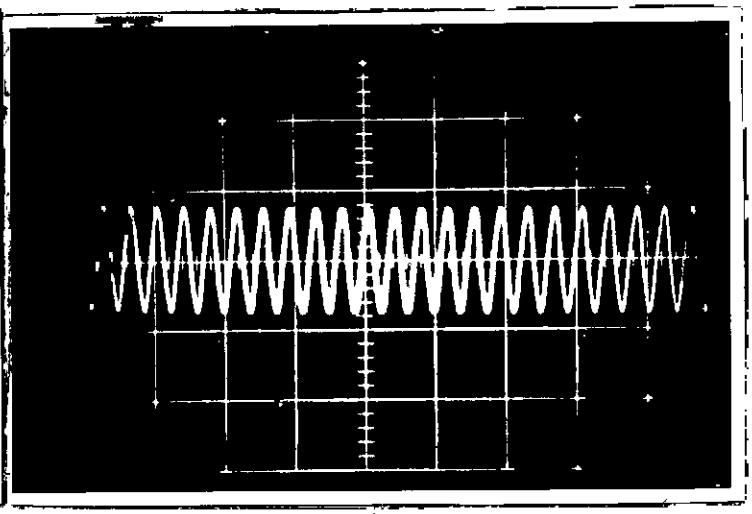


RESISTANCE ≐ 1.719 ohms
INDUCTANCE ≐ 100.34 mH
SPEED ≐ 50 m sec/cm
SENSITIVITY= 0.05 V/cm
RELAY OPERATING
TIME = 1.98 sec.
(7)

PLATE 3A
(NON-TRANSIENT)



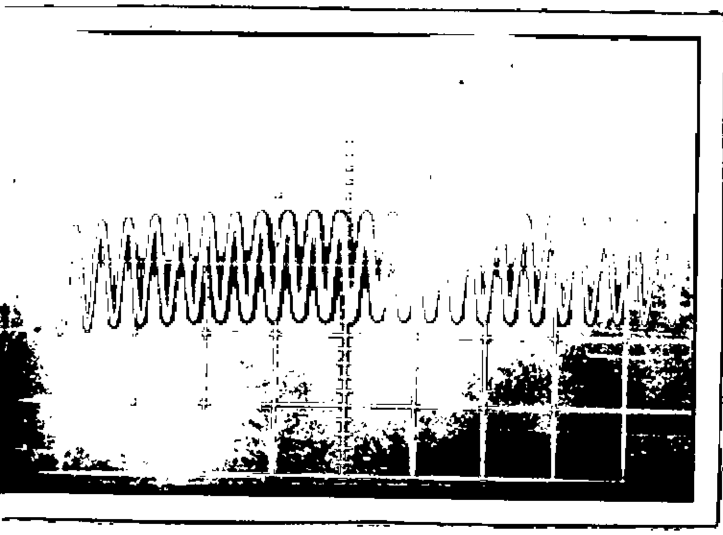
RESISTANCE = 1.719 ohms
INDUCTANCE = 100.34 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.96 sec
(10)



RESISTANCE = 1.719 ohms
INDUCTANCE = 100.34 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.98 sec.
(9)

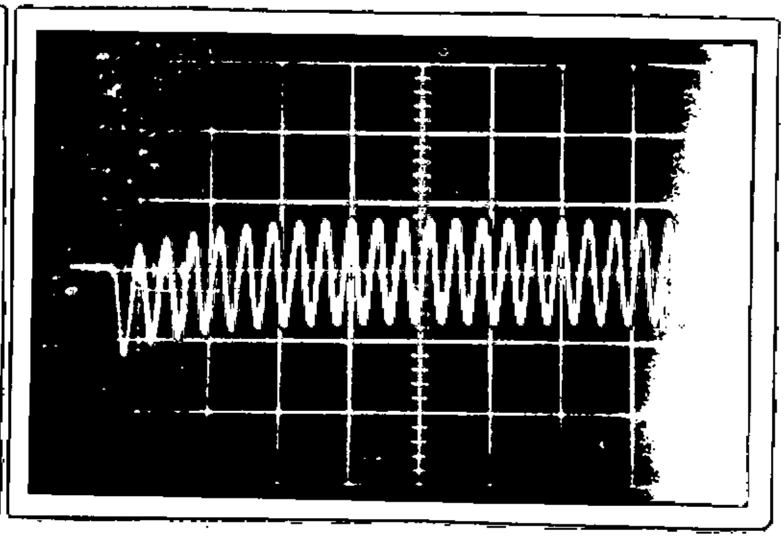
PLATE 3B

(TRANSIENT)



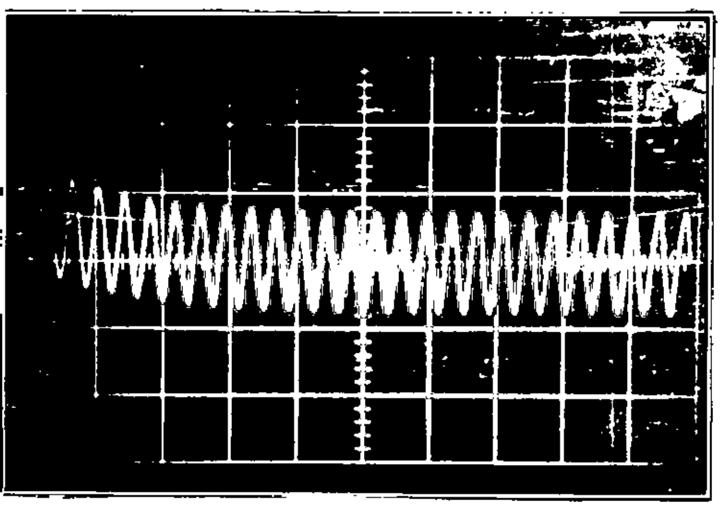
RESISTANCE = 1.498 ohms
INDUCTANCE = 126.5 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.44 sec
PEAK = -164.3%

(2)



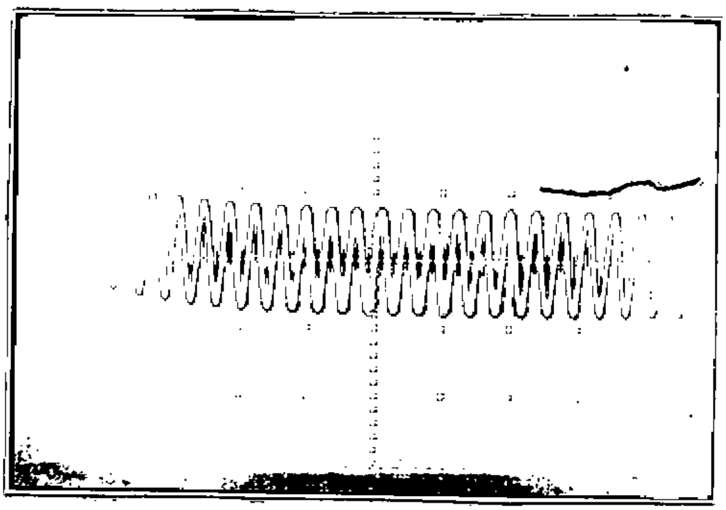
RESISTANCE = 1.498 ohms
INDUCTANCE = 126.5 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.46 sec
PEAK = 157.1%

(1)



RESISTANCE = 1.498 ohms
INDUCTANCE = 126.5 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.42 sec
PEAK = +178.5%

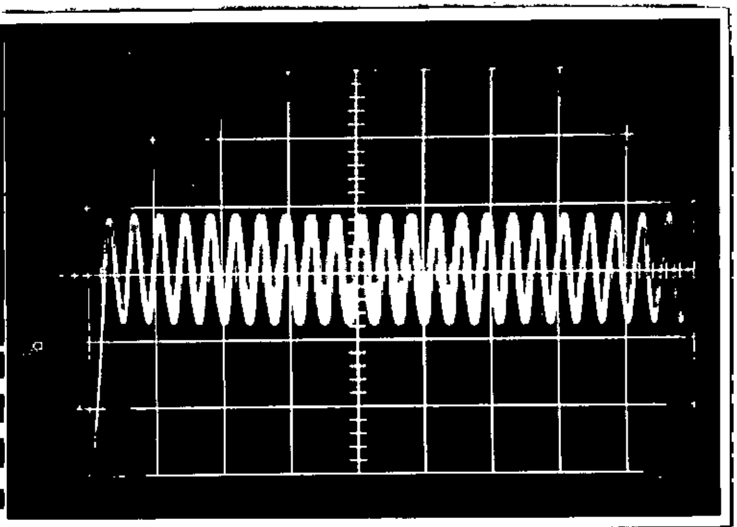
(4)



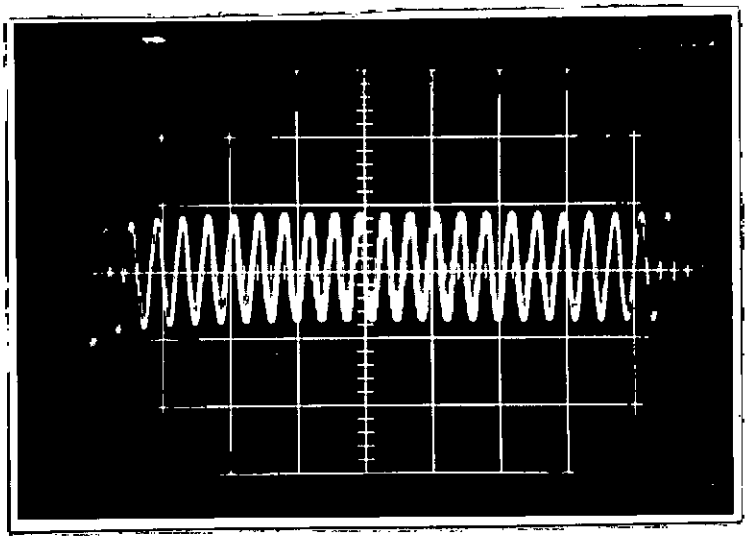
RESISTANCE = 1.498 ohms.
INDUCTANCE = 126.5 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.41 sec
PEAK = +185.5%

(3)

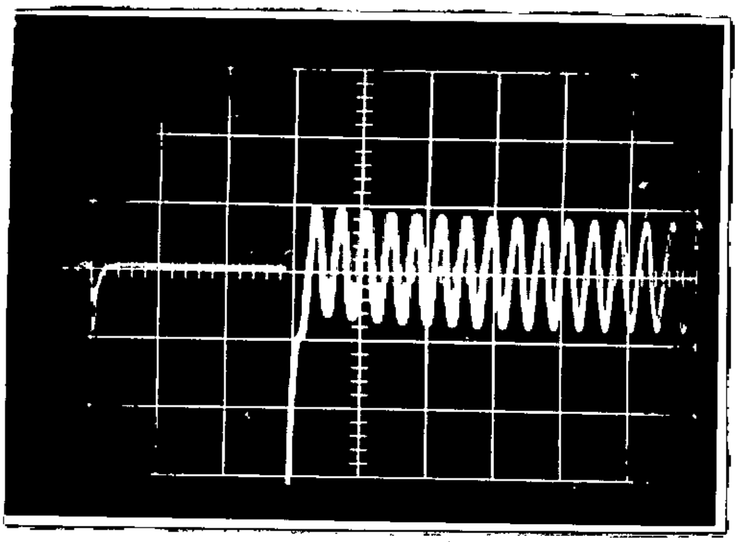
PLATE 3B
(NON-TRANSIENT)



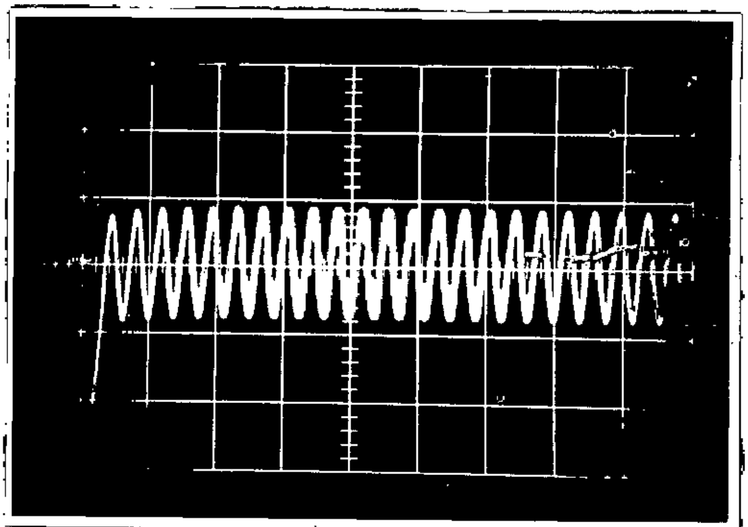
RESISTANCE = 1.498 ohms
INDUCTANCE = 126.5 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.54 sec
(2)



RESISTANCE = 1.498 ohms
INDUCTANCE = 126.5 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.53 sec
(1)

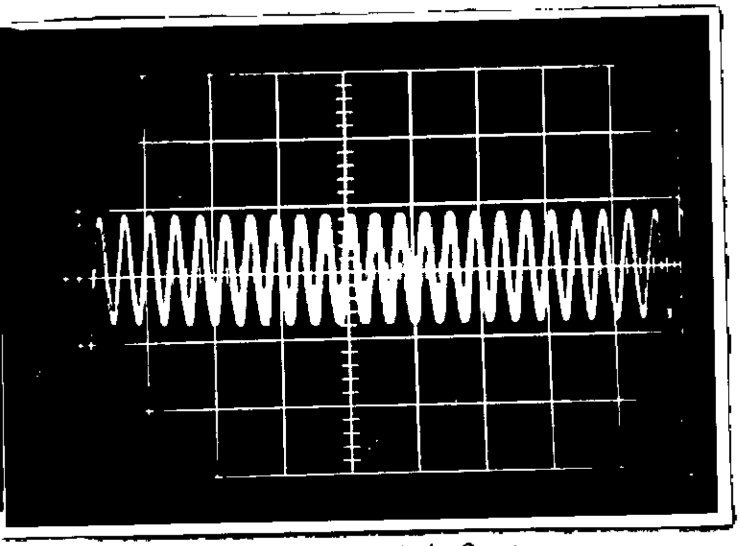


RESISTANCE = 1.498 ohms
INDUCTANCE = 126.5 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.535 sec
(4)

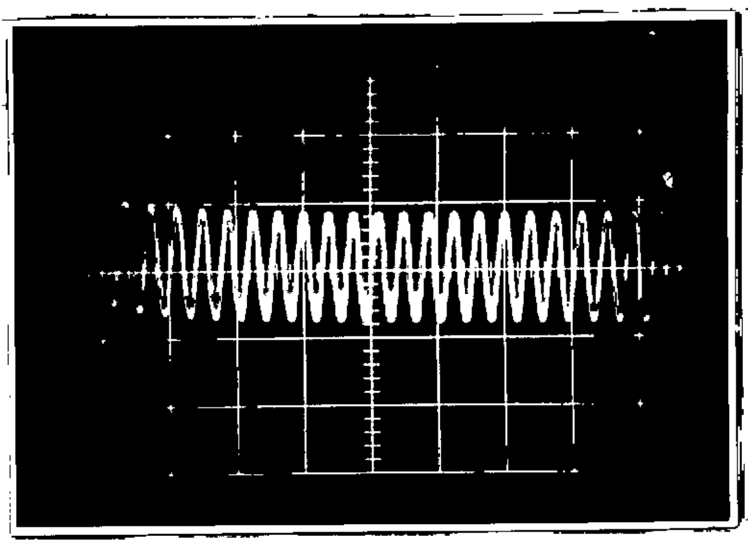


RESISTANCE = 1.498 ohms
INDUCTANCE = 126.5 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.54 sec
(3)

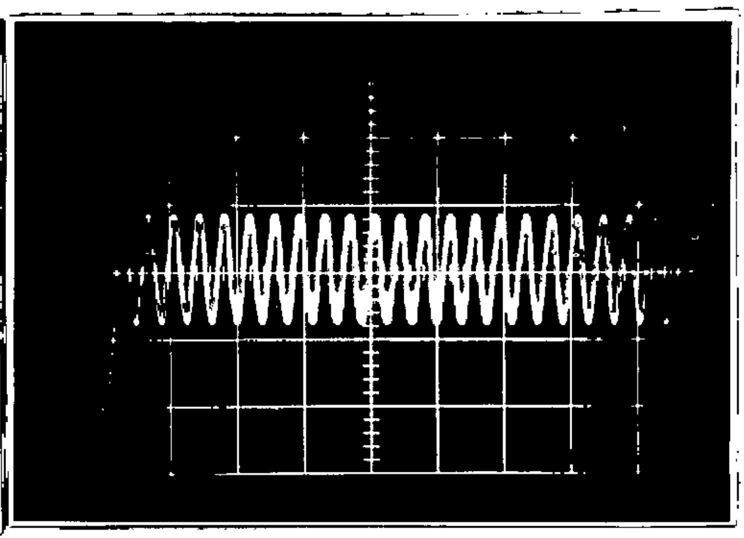
PLATE 3B
(NON-TRANSIENT)



RESISTANCE = 1.498 ohms
INDUCTANCE = 126.5 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.54 sec
(5)

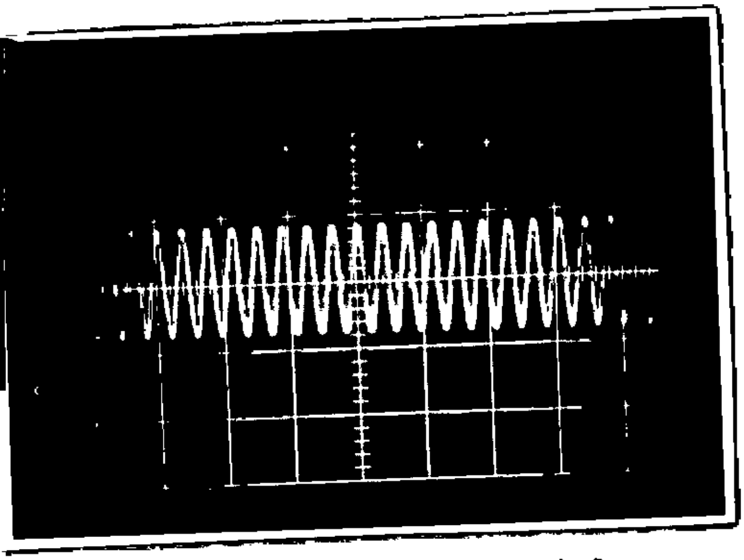


RESISTANCE = 1.498 ohms
INDUCTANCE = 126.5 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.52 sec
(7)



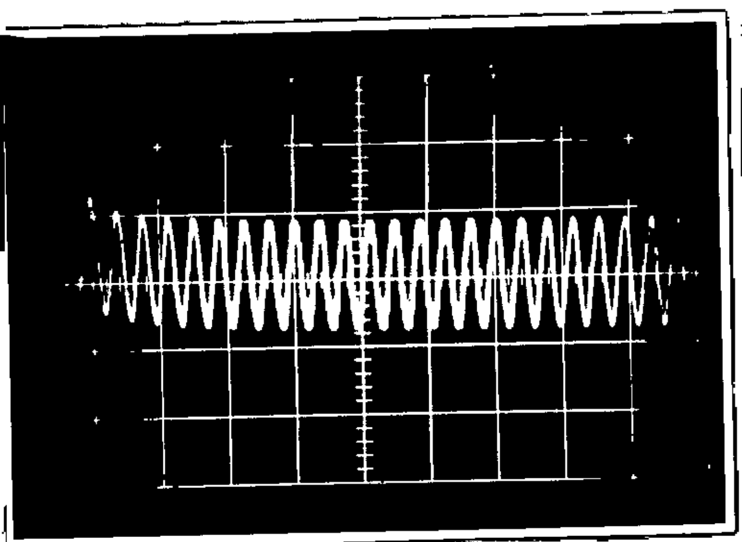
RESISTANCE = 1.498 ohms
INDUCTANCE = 126.5 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.54 sec
(6)

PLATE 3B
(NON-TRANSIENT)

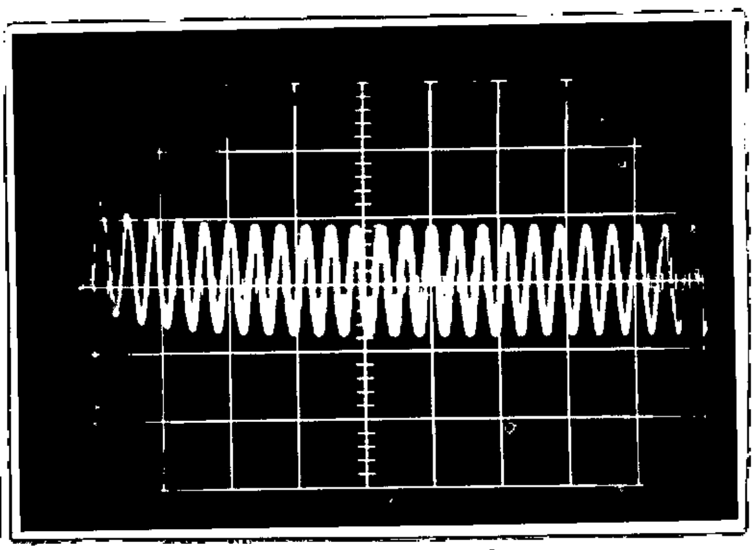


RESISTANCE = 1.498 ohms
INDUCTANCE = 126.5 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.54 sec
(9)

RESISTANCE = 1.498 ohms
INDUCTANCE = 126.5 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.52 sec
(8)

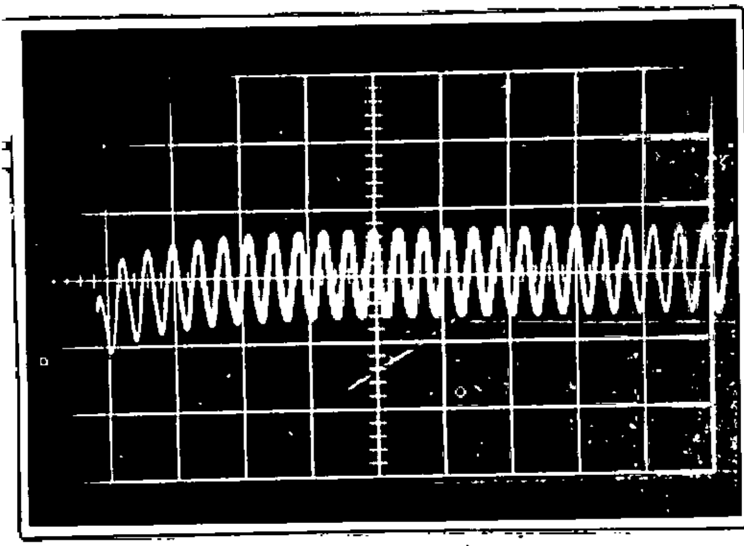


RESISTANCE = 1.498 ohms
INDUCTANCE = 126.5 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.51 sec
(11)



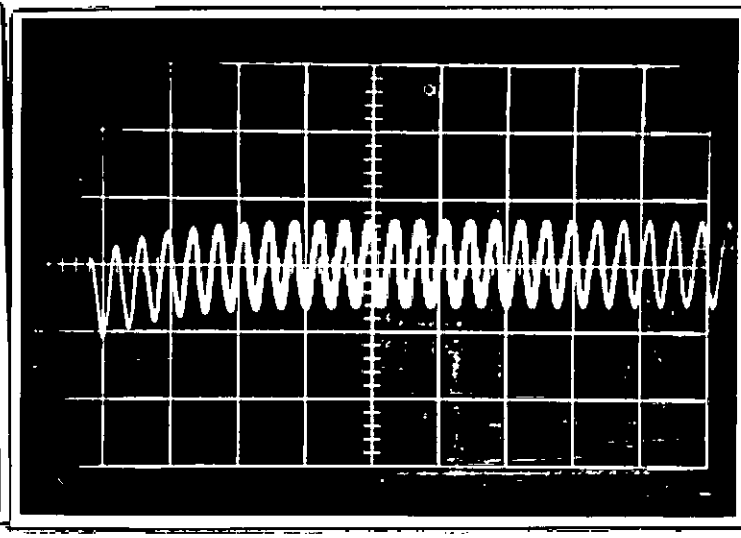
RESISTANCE = 1.498 ohms
INDUCTANCE = 126.5 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 1.51 sec
(10)

PLATE 4
(TRANSIENT)



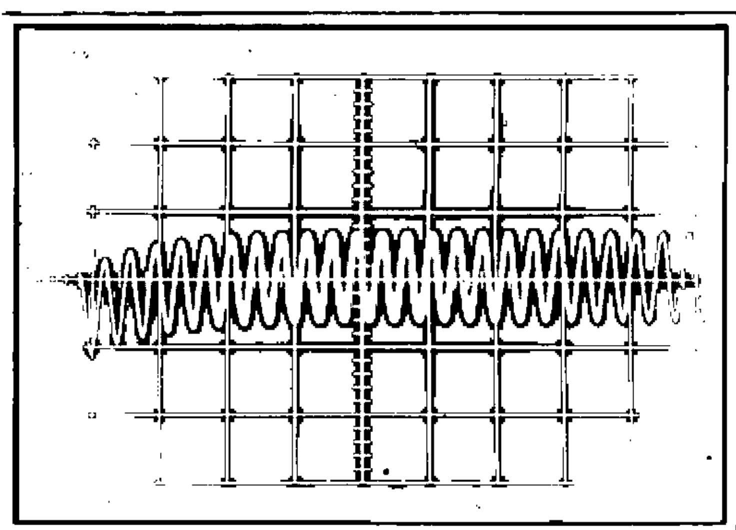
RESISTANCE = 1.0865 ohms
INDUCTANCE = 70.93 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.66 sec
PEAK = -166.6%

(2)



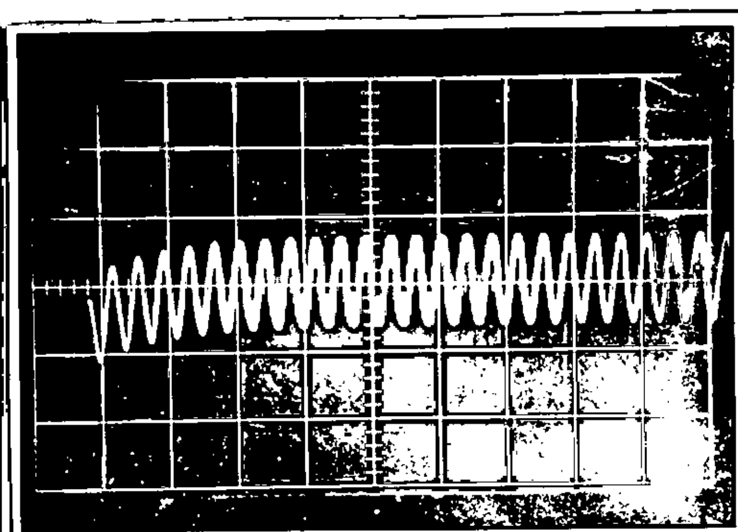
RESISTANCE = 1.0865 ohms
INDUCTANCE = 70.93 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.65 sec
PEAK = -175.1%

(1)



RESISTANCE = 1.0865 ohms
INDUCTANCE = 70.93 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.66 sec
PEAK = -175.1%

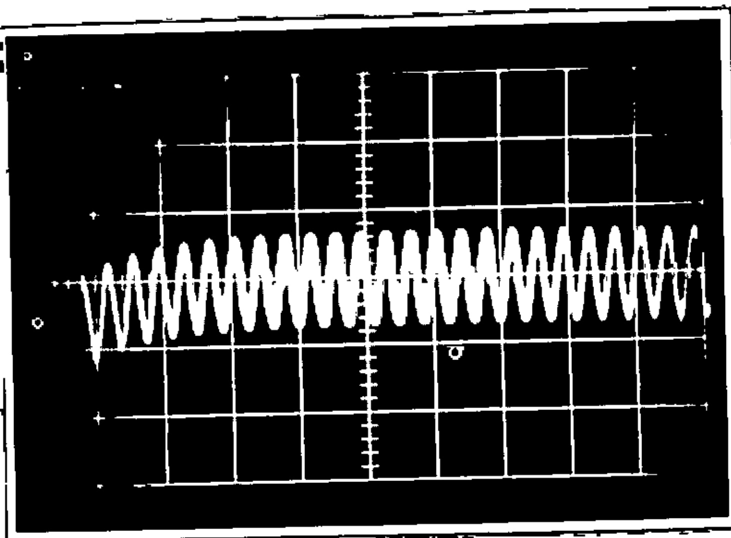
(4)



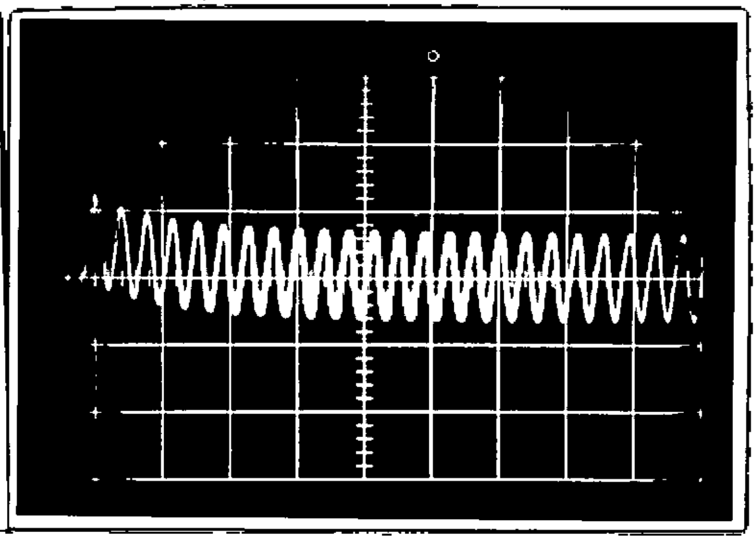
RESISTANCE = 1.0865 ohms
INDUCTANCE = 70.93 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.66 sec
PEAK = -175.1%

(3)

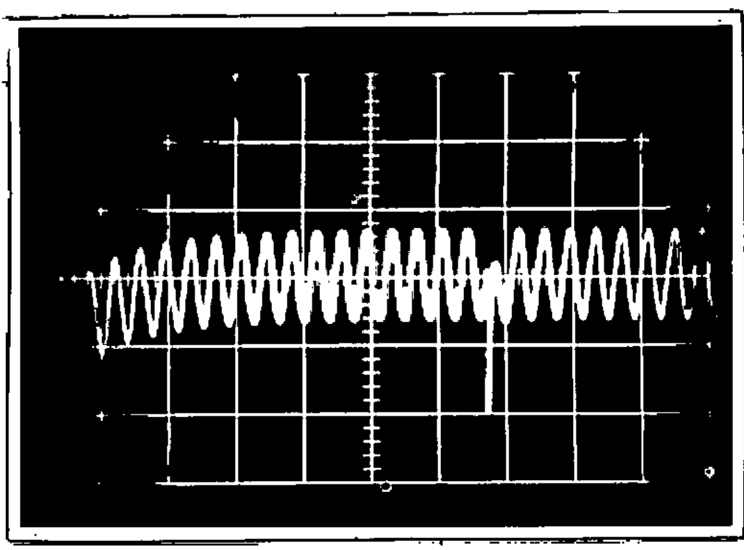
PLATE 4
(TRANSIENT)



RESISTANCE = 1.0865 ohms
INDUCTANCE = 70.93 mH
SPEED ≠ 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.65 sec
PEAK = -175.1%

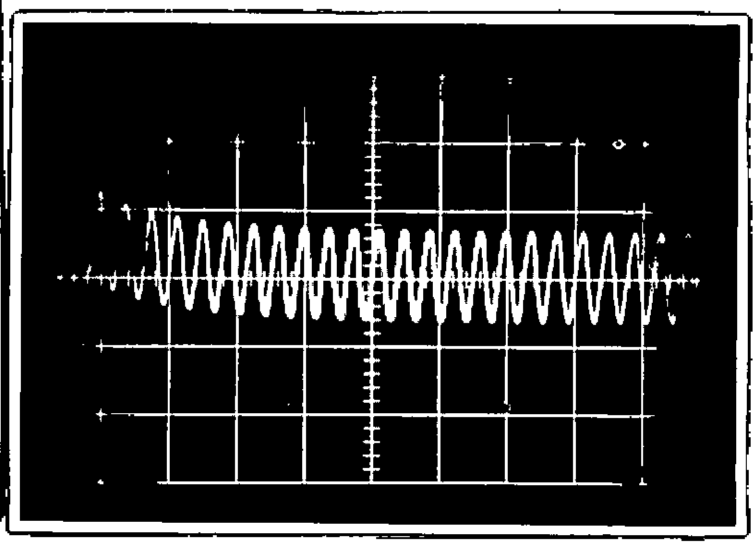


RESISTANCE ≐ 1.0865 ohms
INDUCTANCE = 70.93 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.63 sec
PEAK = +183.3%



RESISTANCE = 1.0865 ohms
INDUCTANCE = 70.93 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.65 sec
PEAK = -175.1%

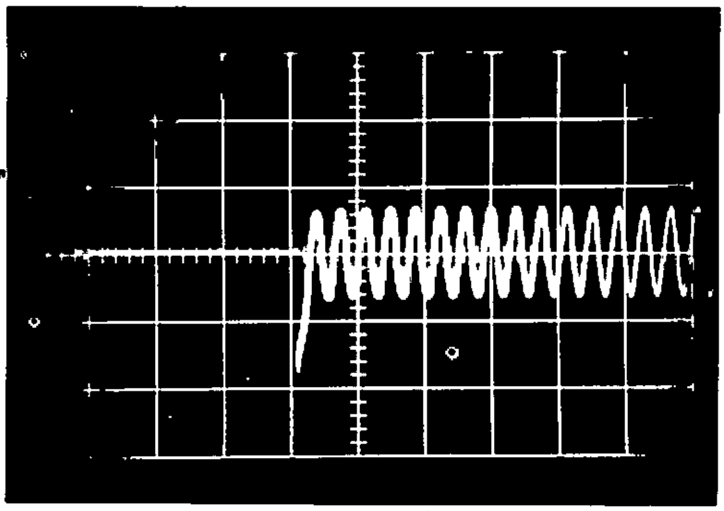
(8)



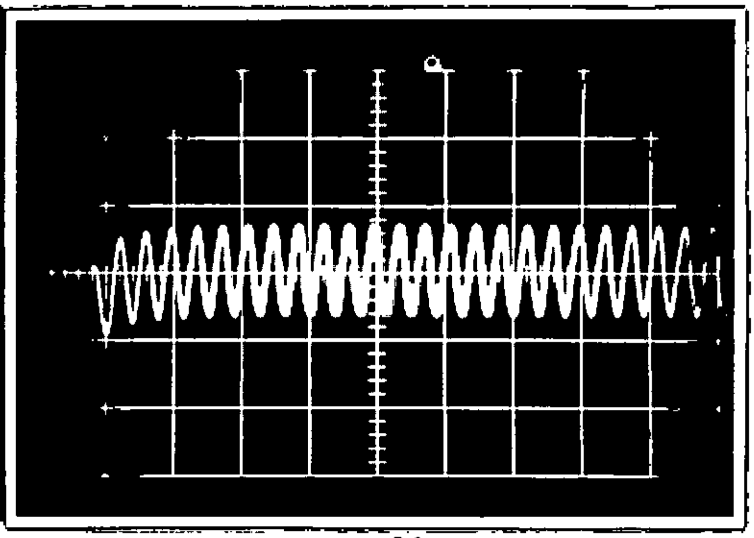
RESISTANCE ≐ 1.0865 ohms
INDUCTANCE = 70.93 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.63 sec.
PEAK = 183.3%

(7)

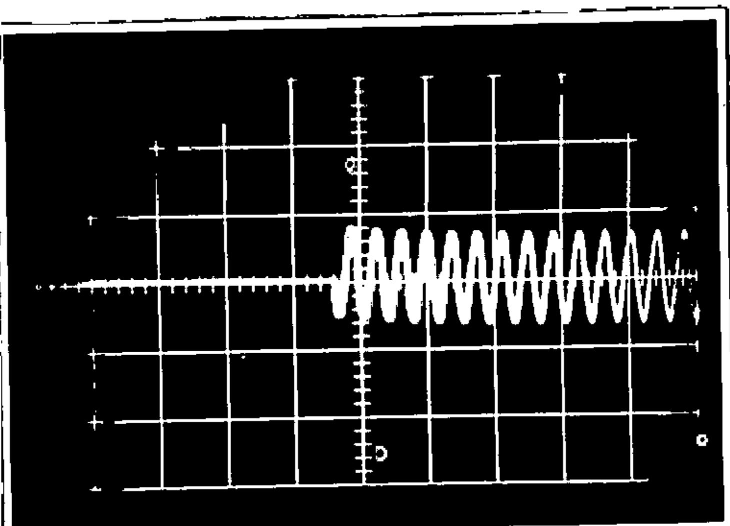
PLATE 4
(NON-TRANSIENT)



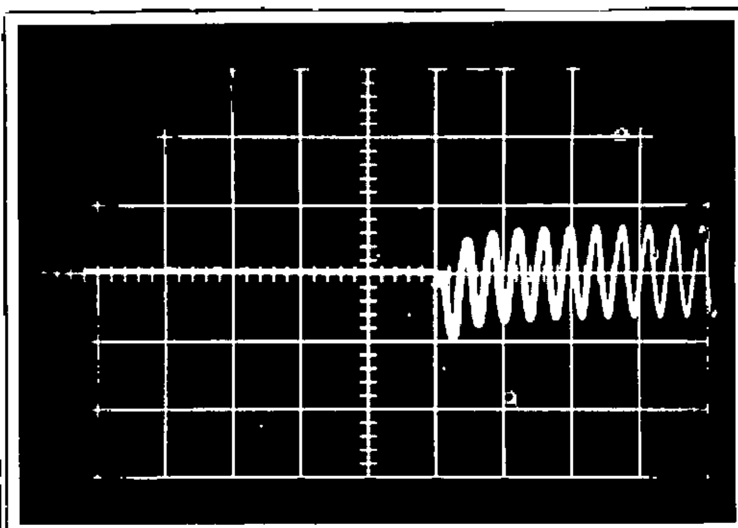
RESISTANCE = 1:0865 ohms
INDUCTANCE = 70.93 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0:71 sec
(2)



RESISTANCE = 1.0865 ohms
INDUCTANCE = 70.93 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.70 sec
(1)

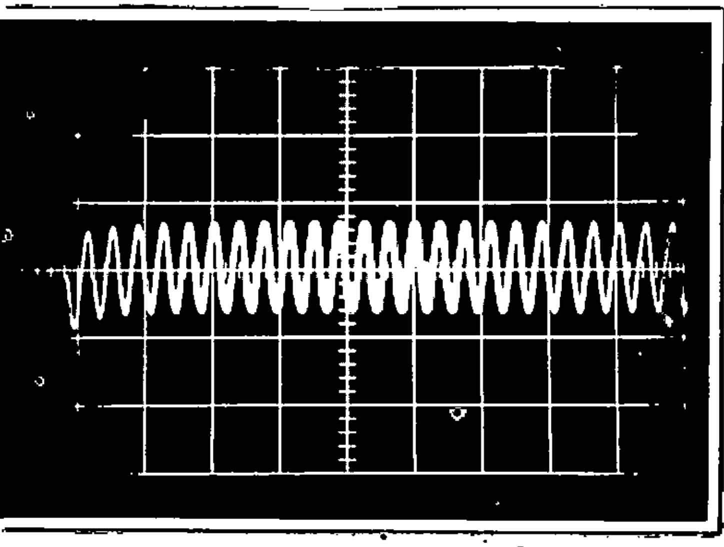


RESISTANCE = 1.0865 phms
INDUCTANCE = 70.93 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.72 sec
(4)

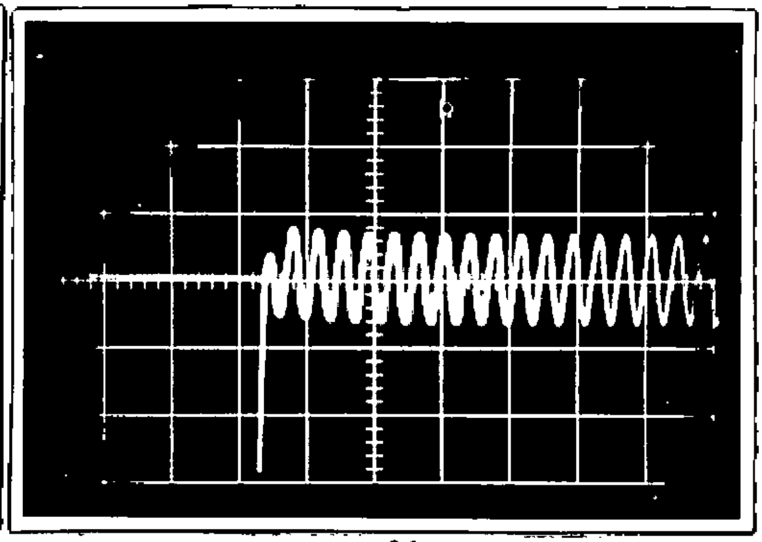


RESISTANCE = 1.0865 ohms
INDUCTANCE = 70.93 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.70 sec
(3)

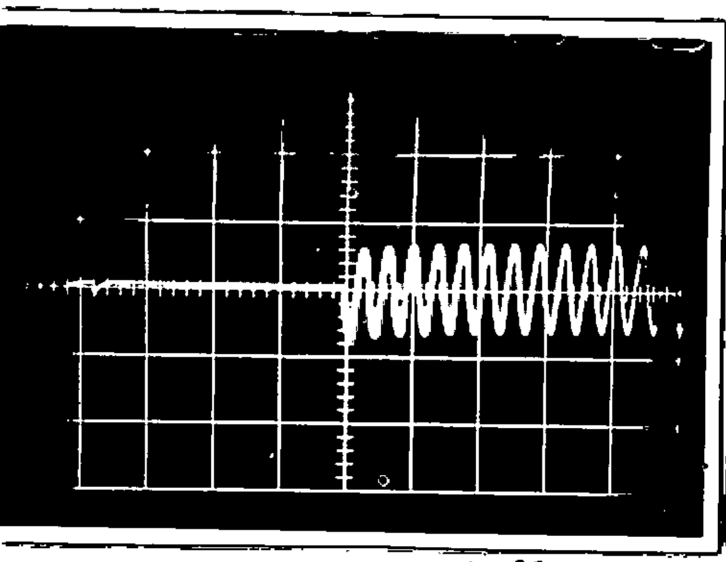
PLATE 4
(NON-TRANSIENT)



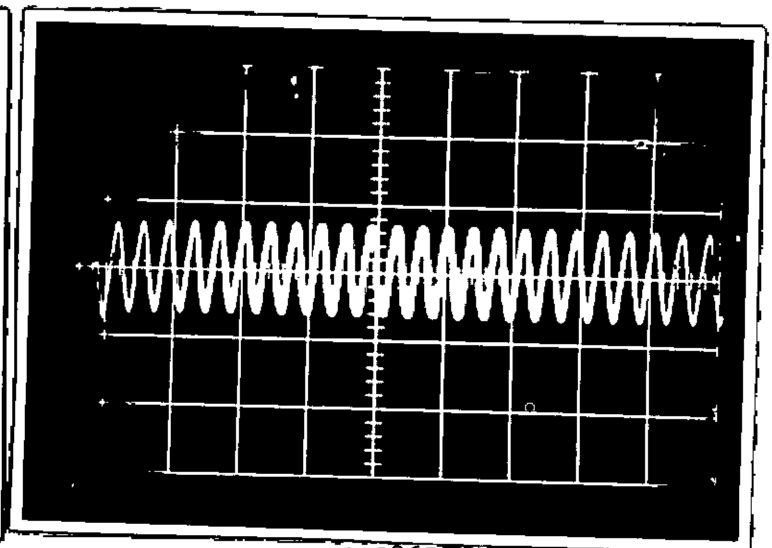
RESISTANCE = 1.0865 ohms
INDUCTANCE = 70.93 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.71 sec
(6)



RESISTANCE = 1.0865 ohms
INDUCTANCE = 70.93 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.70 sec
(5)

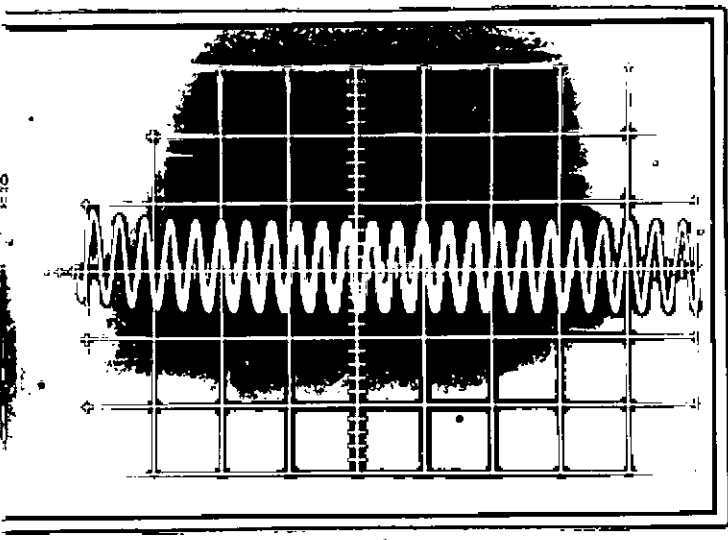


RESISTANCE = 1.0865 ohms
INDUCTANCE = 70.93 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.72 sec
(8)

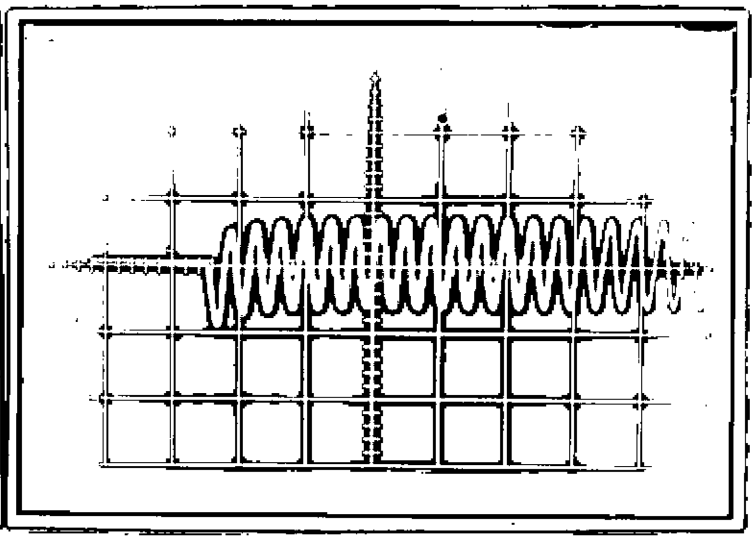


RESISTANCE = 1.0865 ohms
INDUCTANCE = 70.93 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.73 sec
(7)

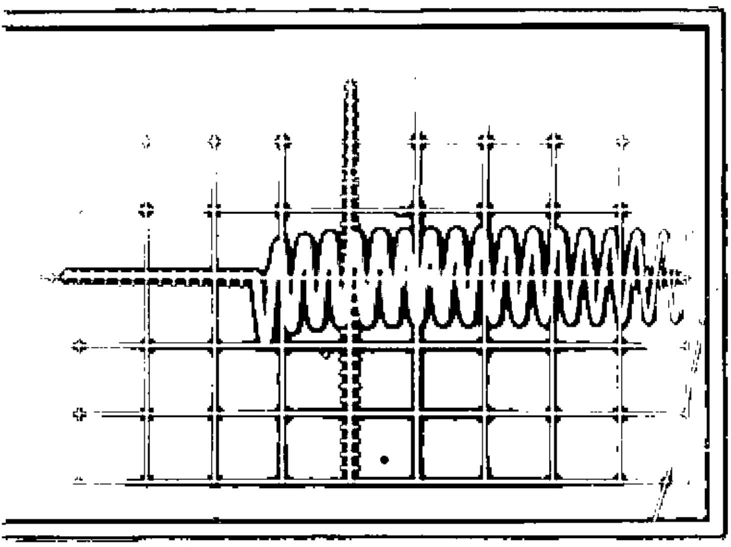
PLATE 4
(NON-TRANSIENT)



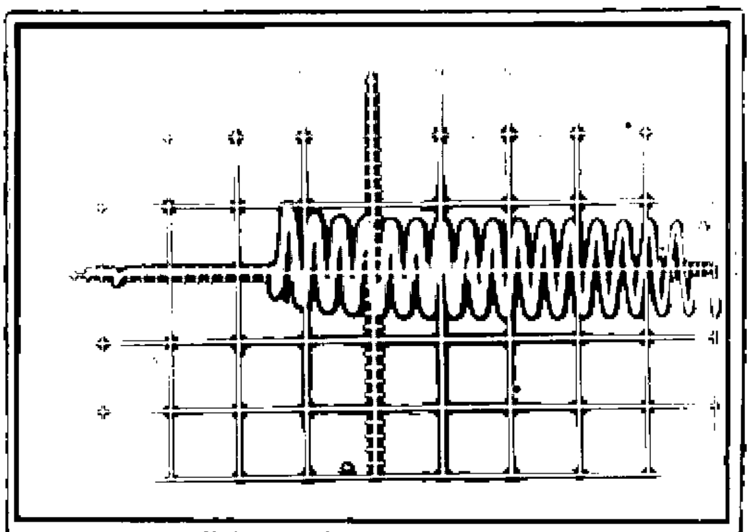
RESISTANCE = 1.0865 ohms
INDUCTANCE = 70.93 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.705sec
(10)



RESISTANCE = 1.0865 ohms
INDUCTANCE = 70.93 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.71 sec
(9)

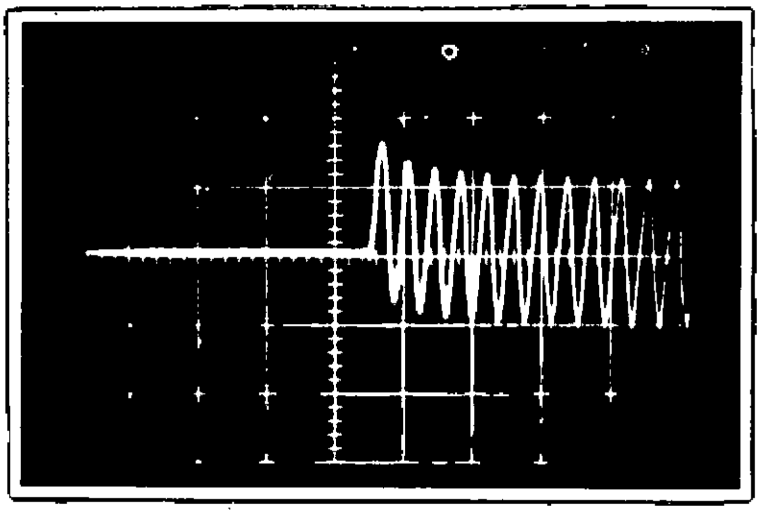


RESISTANCE = 1.0865 ohms
INDUCTANCE = 70.93 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.70 sec
(12)



RESISTANCE = 1.0865 ohms
INDUCTANCE = 70.93 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.05 V/cm
RELAY OPERATING
TIME = 0.70 sec
(11)

PLATE 5
(NON-TRANSIENT)

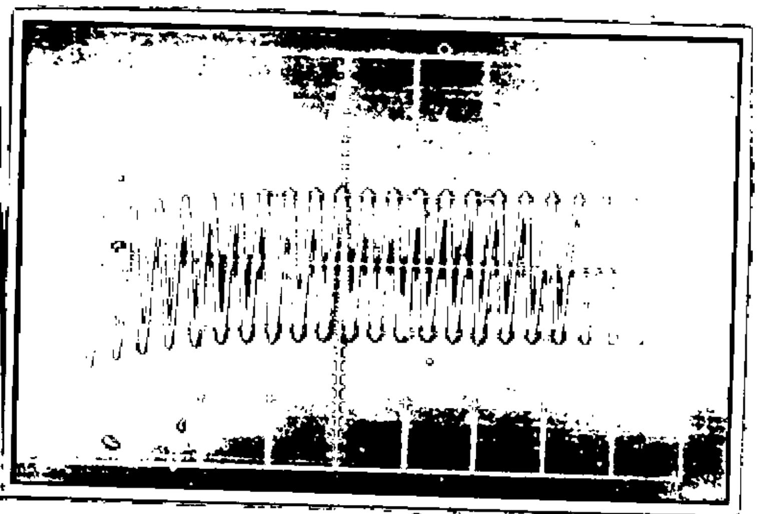


RESISTANCE = 1.280 ohms
INDUCTANCE = 103.13 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.02 V/cm
RELAY OPERATING
TIME = 0.43 sec
(1)

PLATE 5
(TRANSIENT)

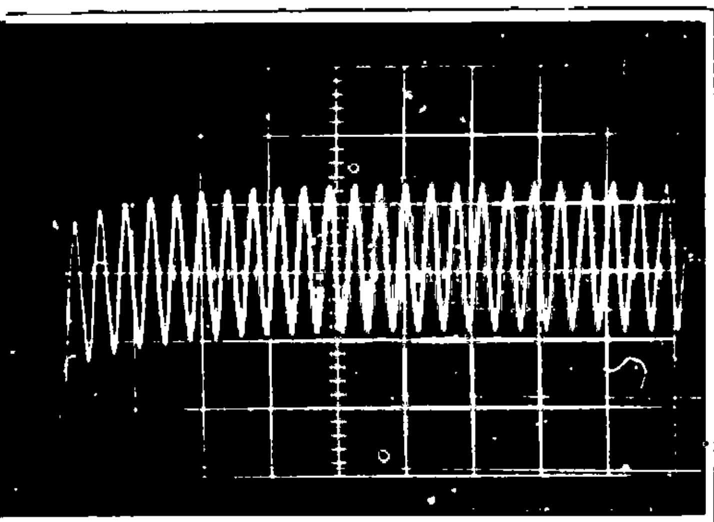
RESISTANCE = 1.280 ohms
INDUCTANCE = 103.13 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.02 V/cm
RELAY OPERATING
TIME = 0.33 sec
PEAK = +172.0%

(2)



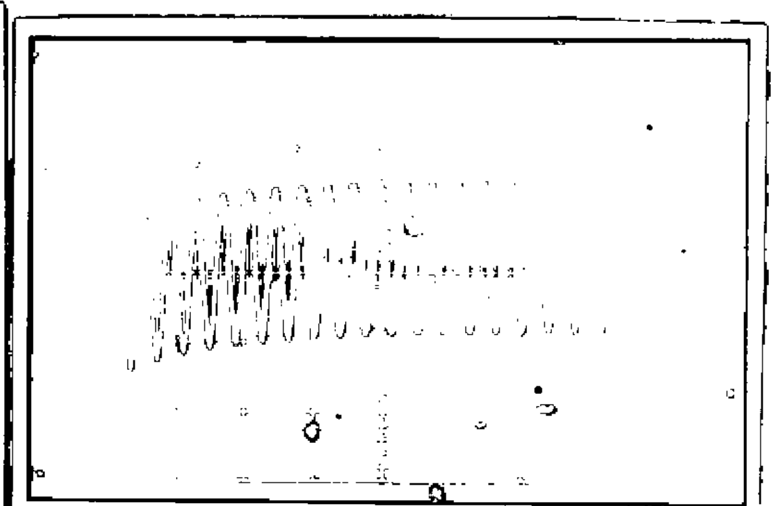
RESISTANCE = 1.280 ohms
INDUCTANCE = 103.13 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.02 V/cm
RELAY OPERATING
TIME = 0.35 sec
PEAK = -165%

(1)



RESISTANCE = 1.280 ohms
INDUCTANCE = 103.13 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.02 V/cm
RELAY OPERATING
TIME = 0.38 sec
PEAK = -135%

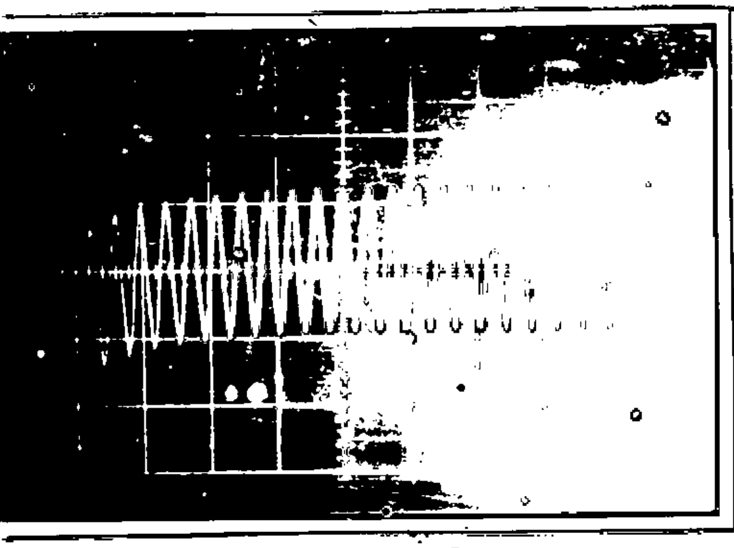
(4)



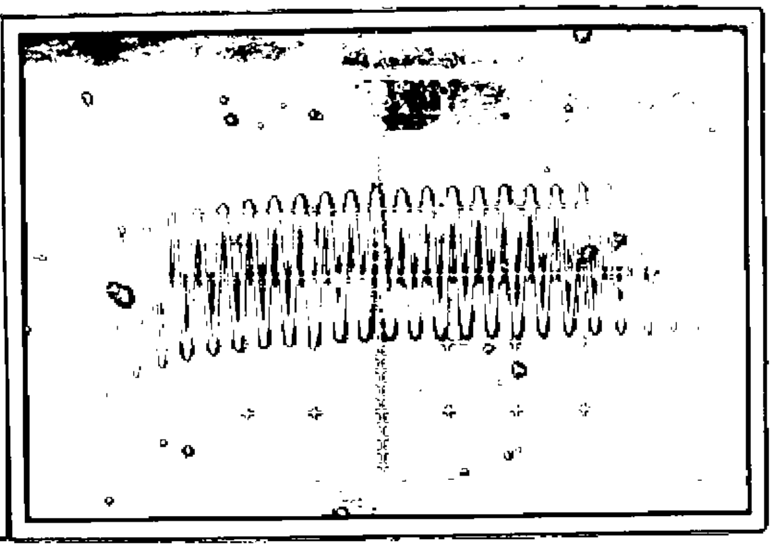
RESISTANCE = 1.280 ohms
INDUCTANCE = 103.13 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.02 V/cm
RELAY OPERATING
TIME = 0.36 sec
PEAK = -162%

(3)

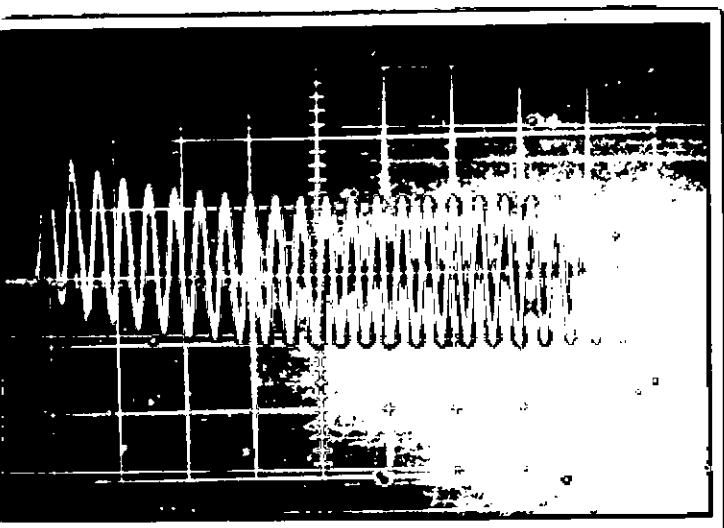
PLATE 5
(TRANSIENT)



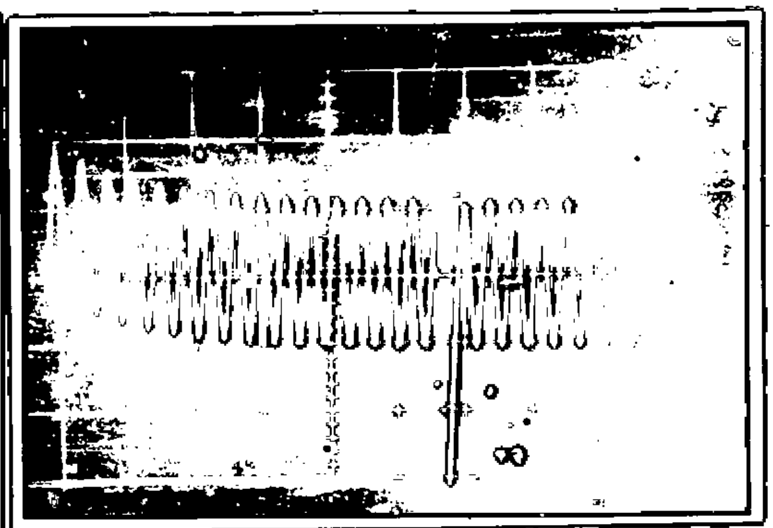
RESISTANCE = 1.280 ohms
INDUCTANCE = 103.13 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.02 V/cm
RELAY OPERATING
TIME = 0.37 sec
PEAK = -14.0%
(6)



RESISTANCE = 1.280 ohms
INDUCTANCE = 103.13 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.02 V/cm
RELAY OPERATING
TIME = 0.32 sec
PEAK = -175%
(5)

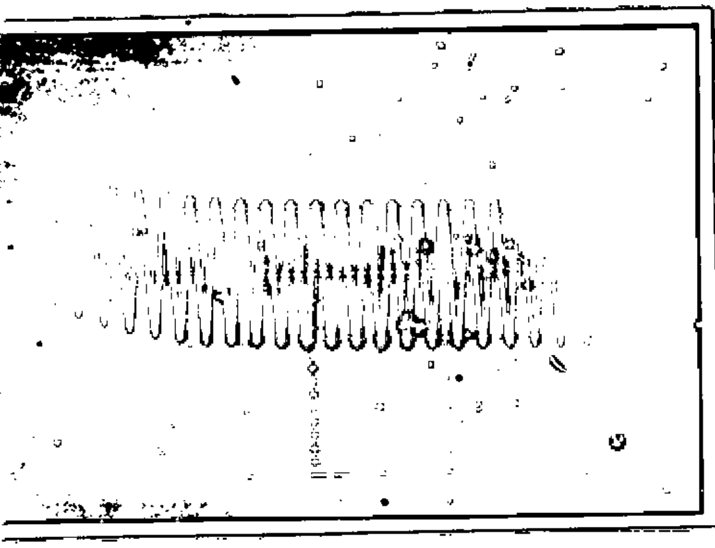


RESISTANCE = 1.280 ohms
INDUCTANCE = 103.13 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.02 V/cm
RELAY OPERATING
TIME = 0.32 sec
PEAK = +175%
(8)



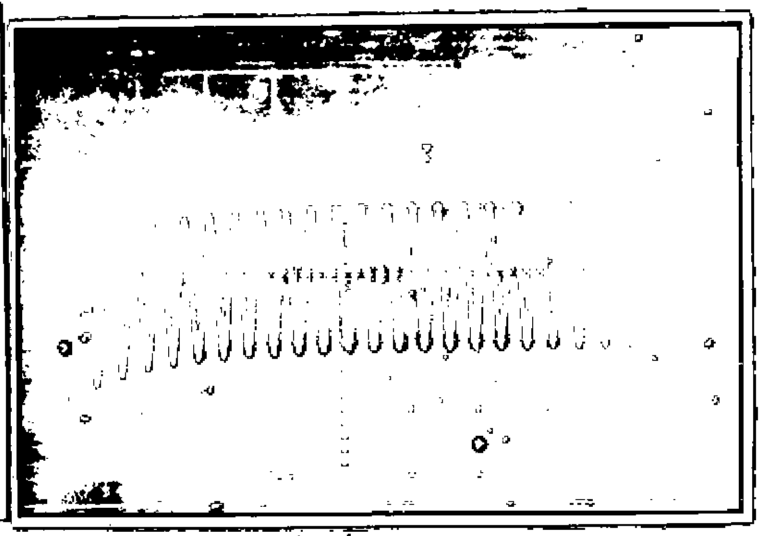
RESISTANCE = 1.280 ohms
INDUCTANCE = 103.13 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.02 V/cm
RELAY OPERATING
TIME = 0.32
PEAK = +175%
(7)

PLATE 5
(TRANSIENT)



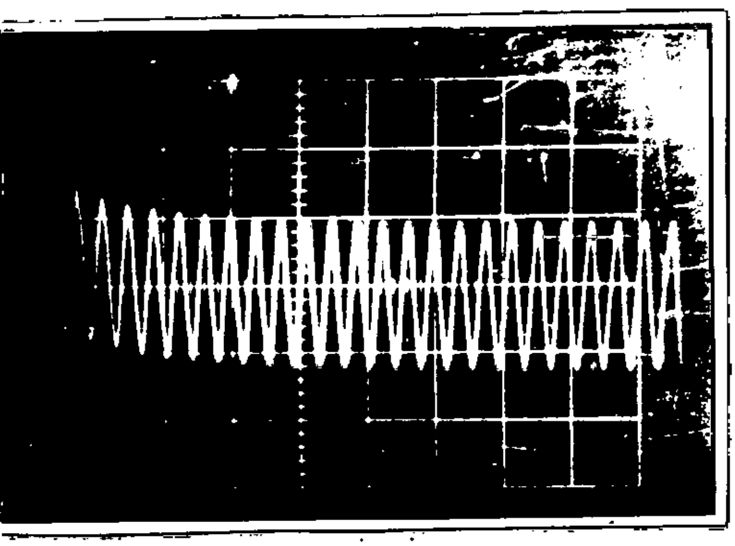
RESISTANCE = 1.280 ohms
INDUCTANCE = 103.13 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.02 V/cm
RELAY OPERATING
TIME = ~~+170%x~~ 0.33 sec
PEAK = +170%

(10)



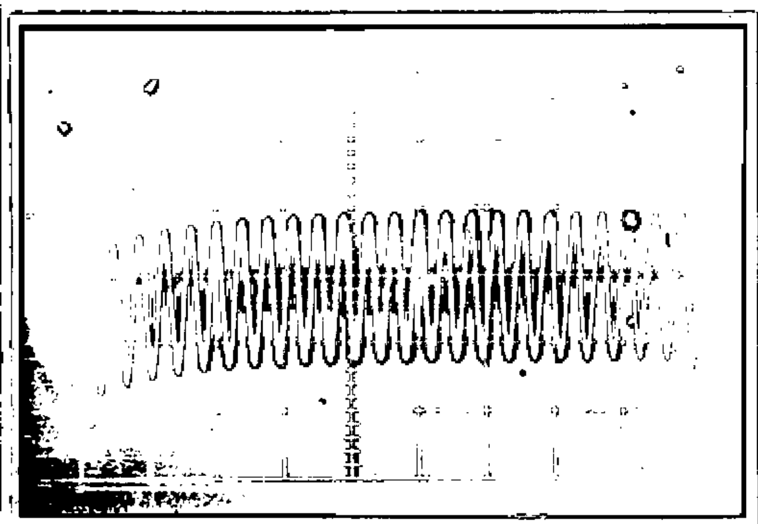
RESISTANCE = 1.280 ohms
INDUCTANCE = 103.13 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.02 V/cm
RELAY OPERATING
TIME = ~~+x~~ 0.35 sec
PEAK = -165%

(9)



RESISTANCE = 1.280 ohms
INDUCTANCE = 103.13 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.02 V/cm
RELAY OPERATING
TIME = 0.31 sec
PEAK = +178%

(12)



RESISTANCE = 1.280 ohms
INDUCTANCE = 103.13 mH
SPEED = 50 m sec/cm
SENSITIVITY = 0.02 V/cm
RELAY OPERATING
TIME = 0.30 sec
PEAK = -180%

(11)

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APPENDIX

TABLE - I

DETERMINATION OF STANDARD DEVIATION.

Sl. No.	Operating time	$(X - \bar{X})$	$(X - \bar{X})^2$	Sl. No.	Operating time	$(X - \bar{X})$	$(X - \bar{X})^2$
1.	2.54	- 0.03	0.0009	1.	2.50	0.004	0.000016
2.	2.54	- 0.03	0.0009	2	2.48	0.016	0.000256
3.	2.565	- 0.005	0.000025	3.	2.445	0.051	0.002601
4.	2.575	+ 0.005	0.000025	4.	2.58	0.084	0.007056
5.	2.57	0	0	5.	2.49	0.006	0.000036
6.	2.60	+ 0.03	0.0009	6.	2.455	0.041	0.001687
7.	2.58	+ 0.01	0.0001	7.	2.585	0.089	0.008021
8.	2.56	- 0.01	0.0001	8.	2.47	0.026	0.000676
9.	2.585	+ 0.015	0.000225	9.	2.495	0.001	0.000001
10.	2.60	+ 0.03	0.0009	10.	2.45	0.046	0.002116
11.	2.59	0.02	0.0004	11.	2.43	0.066	0.004356
12.	2.58	0.01	0.0001	12.	2.50	0.004	0.000016
13.	2.595	0.025	0.000625	13.	2.58	0.084	0.007056
14.	2.57	0	0	14.	2.56	0.064	0.004096
15.	2.565	- 0.005	0.000025	15.	2.54	0.044	0.001936
16.	2.575	+ 0.005	0.000025	16.	2.56	0.064	0.004096
17.	2.56	- 0.01	0.0001	17.	2.445	0.051	0.002601
18.	2.53	- 0.04	0.0016	18.	2.45	0.046	0.002116
19.	2.52	- 0.05	0.0025	19.	2.445	0.051	0.00260
20.	2.60	+ 0.03	0.0009	20.	2.44	0.056	0.003136
			0.010350				0.054470

Arithmetic Mean $= \bar{X} = \frac{51.400}{20}$

$= 2.57$

Standard deviation

$$= \sigma = \sqrt{\frac{(X - \bar{X})^2}{N}} = \frac{0.01035}{20}$$

$= 0.0005175 \quad = 0.0227$

$\therefore \quad \sigma = 0.0227$

Arithmetic Mean $= \bar{X} = \frac{49.920}{20}$

$= 2.496$

Standard deviation

$$= \sigma = \sqrt{\frac{(X - \bar{X})^2}{N}} = \sqrt{\frac{0.054470}{20}}$$

$= 0.0521$

$\therefore \quad = 0.0521$

TABLE - II

Sl. No.	Operating time of the relay (without regulator)	$(X - \bar{X})$	$(X - \bar{X})^2$
1.	2.45 sec.	- 0.05	0.0025
2.	2.49 ,,	- 0.01	0.0001
3.	2.44 ,,	- 0.06	0.0036
4.	2.48 ,,	- 0.02	0.0004
5.	2.55 ,,	+ 0.05	0.0025
6.	2.50 ,,	0	0
7.	2.50 ,,	0	0
8.	2.58 ,,	+ 0.08	0.0064
9.	2.53 ,,	+ 0.03	0.0009
10.	2.59 ,,	+ 0.09	0.0081
11.	2.43 ,,	- 0.07	0.0049
12.	2.55 ,,	+ 0.05	0.0025
13.	2.45 ,,	- 0.05	0.0025
14.	2.47 ,,	- 0.03	0.0009
15.	2.43 ,,	- 0.07	0.0049
16.	2.45 ,,	- 0.05	0.0025
17.	2.43 ,,	- 0.07	0.0049
18.	2.56 ,,	+ 0.06	0.0036
19.	2.58 ,,	+ 0.08	0.0064
20.	2.54 ,,	+ 0.04	0.0016
	50.00 sec		0.0602

Arithmetic Mean $\bar{X} = \frac{50.00}{20}$

$= 2.50$

Standard deviation

$$= \alpha = \sqrt{\frac{(X - \bar{X})^2}{N}}$$

$$= \sqrt{\frac{0.0602}{20}}$$

$$= \sqrt{0.00301}$$

$$= 0.0548$$

T A B L E - III

CALCULATION OF STANDARD DEVIATION

Sl. No.	Operating time of the relay for transient operation	$(X - \bar{X})$	$(X - \bar{X})^2$	Sl. No.	Operating time of the relay for non-transient operation	$(X-\bar{X})$	$(X - \bar{X})^2$
1.	0.83 secs.	-0.035	0.001225	1.	0.935	+0.005	0.000025
2.	0.88 ,,	+0.015	0.000225	2.	0.935	+0.005	0.000025
3.	0.915 ,,	+0.050	0.002500	3.	0.93	0	0
4.	0.90 ,,	+0.035	0.001225	4.	0.93	0	0
5.	0.845 ,,	-0.02	0.000400	5.	0.94	+0.010	0.000100
6.	0.84 ,,	-0.025	0.000625	6.	0.93	0	0
7.	0.87 ,,	+0.005	0.000025	7.	0.92	-0.010	0.000100
8.	0.85 ,,	-0.015	0.000225	8.	0.935	+0.005	0.000025
9.	0.85 ,,	-0.015	0.000225	9.	0.94	+0.010	0.000100
10.	0.87 ,,	+0.005	0.000025	10.	0.93	0	0
~~11~~				11.	0.935	+0.005	0.000025
	8.65		0.006700		10.23		0.000400

Arithmetic Mean $= \bar{X} = \frac{8.65}{10}$

$= 0.865$ sec.

Standard deviation

$$= \alpha = \sqrt{\frac{(X - \bar{X})}{N}} = \sqrt{\frac{0.006700}{10}}$$

$$= \sqrt{0.00067} = 0.0258$$

Arithmetic Mean $= \bar{X} = \frac{10.23}{11}$

$= 0.93$ sec.

Standard deviation

$$= \alpha = \sqrt{\frac{(X-\bar{X})^2}{N}}$$

$$= \sqrt{\frac{0.0004}{11}}$$

$$= \sqrt{0.00003636} = 0.00603$$

TABLE - IV A

CALCULATION OF STANDARD DEVIATION

Sl. No.	Operating time for transient operation	$(X - \bar{X})$	$(X - \bar{X})^2$
1.	0.66 sec.	+0.034	0.001156
2.	0.625 ,,	-0.001	0.000001
3.	0.625 ,,	-0.001	0.000001
4.	0.63 ,,	+0.004	0.000016
5.	0.625 ,,	-0.001	0.000001
6.	0.58 ,,	-0.046	0.002116
7.	0.03 ,,	+0.004	0.000016
8.	0.63 ,,	+0.004	0.000016
9.	0.63 ,,	+0.004	0.000016
10.	0.625 ,,	-0.001	0.000001
11.	6.260		0.003340

Arithmetic Mean $= \bar{X} = \frac{6.260}{10}$

$= 0.626$

Standard deviation

$$= \alpha = \sqrt{\frac{(X-\bar{X})^2}{N}}$$

$$= \sqrt{\frac{0.003340}{10}}$$

$$= \sqrt{0.000334}$$

$$= 0.0183$$

Sl. No.	Operating time for relay for non-transient operation	$(X - \bar{X})$	$(X - \bar{X})^2$
1.	0.69 sec.	+0.008	0.000064
2.	0.68 ,,	-0.002	0.000004
3.	0.69 ,,	+0.008	0.000064
4.	0.68 ,,	-0.002	0.000004
5.	0.69 ,,	+0.008	0.000064
6.	0.68 ,,	-0.002	0.000004
7.	0.67 ,,	-0.012	0.000147
8.	0.67 ,,	-0.012	0.000147
9.	0.68 ,,	-0.002	0.000004
10.	0.69 ,,	+0.008	0.000064
	6.82		0.000560

Arithmetic Mean $= \bar{X} = \frac{6.82}{10}$

$= 0.682$

Standar-d Deviation

$$= \alpha = \sqrt{\frac{(X-\bar{X})^2}{N}}$$

$$= \sqrt{\frac{0.000560}{10}}$$

$$= \sqrt{0.000056}$$

$$= 0.00749$$

TABLE - IV B

CALCULATION OF STANDARD DEVIATION

Sl. No.	Operating time for transient operation	$(X - \bar{X})$	$(X - \bar{X})^2$	Sl. No.	Operating time for non-transient operation	$(X - \bar{X})$	$(X - \bar{X})^2$
1.	0.87 sec.	-0.01	0.0001	1.	1.07 sec.	-0.001	0.000001
2.	0.84 ,,	-0.04	0.0016	2.	1.06 ,,	-0.011	0.000121
3.	0.90 ,,	+0.02	0.0004	3.	1.06 ,,	-0.011	0.000121
4.	0.86 ,,	-0.02	0.0004	4.	1.07 ,,	-0.001	0.000001
5.	0.89 ,,	-0.01	0.0001	5.	1.08 ,,	+0.009	0.000081
6.	0.851 ,,	-0.03	0.0009	6.	1.07 ,,	-0.001	0.000001
7.	0.88 ,,	0	0	7.	1.08 ,,	+0.009	0.000081
8.	0.89 ,,	+0.01	0.0001	8.	1.08 ,,	+0.009	0.000081
9.	0.90 ,,	+0.02	0.0004	9.	1.07 ,,	-0.001	0.000001
10.	0.92 ,,	+0.04	0.0016	10.	1.07 ,,	-0.001 (exposed)	0.000001
	8.80		0.0056		10.71		0.00049

Arithmetic Mean $= \bar{X} = \frac{8.80}{10}$

$= 0.880$

Standard deviation

$$= \alpha = \sqrt{\frac{(X - \bar{X})^2}{N}}$$

$$= \sqrt{\frac{0.0056}{10}}$$

$$= \sqrt{0.00056}$$

$$= 0.0237$$

Arithmetic Mean $= \bar{X} = \frac{10.71}{10}$

$= 1.071$

Standard deviation

$$= \alpha = \sqrt{\frac{(X - \bar{X})^2}{N}}$$

$$= \sqrt{\frac{0.00049}{10}}$$

$$= \sqrt{0.000049}$$

$$= 0.007$$

TABLE - V A

CALCULATION OF STANDARD DEVIATION

Sl. No.	Operating time for transient operation	$(X - \bar{X})$	$(X - \bar{X})^2$
1.	1.92 sec.	+0.02	0.0004
2.	1.89 ,,	-0.01	0.0001
3.	1.92 ,,	+0.02	0.0004
4.	1.90 ,,	0	0
5.	1.87 ,,	-0.03	0.0009
6.	1.885 ,,	-0.015	0.000225
7.	1.895 ,,	-0.005	0.000025
8.	1.86 ,,	-0.04	0.0016
9.	1.88 ,,	-0.02	0.0004
10.	1.88 ,,	-0.02	0.0004
	19.00		0.004450

Arithmetic Mean $= \bar{X} = \frac{19.00}{10}$

$= 1.90$ sec.

Standard deviation

$$= \sigma = \sqrt{\frac{(X - \bar{X})^2}{N}}$$

$$= \sqrt{\frac{0.00445}{10}}$$

$$= \sqrt{0.000445}$$

$$= 0.0219$$

Sl. No.	Operating time for non-transient operation	$(X - \bar{X})$	$(X - \bar{X})^2$
1.	1.97 sec.	-0.003	0.000009
2.	1.98 ,,	+0.007	0.000049
3.	1.96 ,,	-0.013	0.000169
4.	1.97 ,,	-0.003	0.000009
5.	1.98 ,,	+0.007	0.000049
6.	1.98 ,,	+0.007	0.000049
7.	1.98 ,,	+0.007	0.000049
8.	1.97 ,,	-0.003	0.000009
9.	1.98 ,,	+0.007	0.000049
10.	1.96 ,,	-0.013	0.000169
	19.73		0.000610

Arithmetic Mean $= \bar{X} = \frac{19.73}{10}$

$= 1.973$ sec.

Standard deviation

$$= \sigma = \sqrt{\frac{(X - \bar{X})^2}{N}}$$

$$= \sqrt{\frac{0.000610}{10}}$$

$$= \sqrt{0.0000610}$$

$$= 0.00781$$

TABLE - V B

CALCULATION OF STANDARD DEVIATION.

Sl. No.	Operating time for transient operation.	$(X - \bar{X})$	$(X - \bar{X})^2$
1.	1.46	+0.027	0.000729
2.	1.44	+0.007	0.000049
3.	1.41	-0.023	0.000529
4.	1.42	-0.013	0.000169
5.	1.40	-0.033	0.001089
6.	1.46	+0.027	0.000729
7.	1.42	-0.013	0.000169
8.	1.44	+0.007	0.00049
9.	1.43	-0.003	0.000009
10.	1.45	+0.017	0.000289
	14.33		0.00381

Sl. No.	Operating time for non-trans. operation.	$(X - \bar{X})$	$(X - \bar{X})^2$
1.	1.53	+0.001	0.000001
2.	1.54	+0.011	0.000121
3.	1.54	+0.011	0.000121
4.	1.52	-0.009	0.000081
5.	1.535	+0.006	0.000036
6.	1.535	+0.006	0.000036
7.	1.54	+0.011	0.000121
8.	1.54	+0.011	0.000121
9.	1.52	-0.009	0.000081
10.	1.52	-0.009	0.000081
11.	1.52	-0.009	0.000081
12.	1.54	+0.011	0.000121
13.	1.51	-0.019	0.000361
14.	1.51	-0.019	0.000361
	21.400		0.001724

Arithmetic Mean $= \bar{X} = \frac{14.33}{10}$

$= 1.433$

Standard deviation

$$= \sqrt{\frac{(X - X)^2}{N}}$$

$$= \sqrt{\frac{0.00381}{10}}$$

$$= \sqrt{0.000381}$$

$= 0.0195$

Arithmetic Mean $= \bar{X} = \frac{21.400}{14}$

$= 1.529$

Standard deviation

$$= \sqrt{\frac{(X - X)^2}{N}}$$

$$= \sqrt{\frac{0.001724}{14}}$$

$$= \sqrt{0.00012315}$$

$= 0.011$

TABLE - VI

CALCULATION OF STANDARD DEVIATION

Sl. No.	Operating time for transient operation	$(X - \bar{X})$	$(X - \bar{X})^2$
1.	0.65	0	0
2.	0.66	+0.01	0.0001
3.	0.65	0	0
4.	0.66	+0.01	0.0001
5.	0.63	-0.02	0.0004
6.	0.65	0	0
7.	0.63	-0.02	0.0004
8.	0.65	0	0
9.	0.64	-0.01	0.0001
10.	0.68 (exp)	+0.03	0.0009
	6.50		0.0020

Arithmetic Mean $= \bar{X} = \frac{6.50}{10}$

$= 0.65$

Standard deviation

$$= \sigma = \sqrt{\frac{(X - \bar{X})^2}{N}}$$

$$= \sqrt{\frac{0.0020}{10}}$$

$$= \sqrt{0.00020}$$

$$= 0.0141$$

Sl. No.	Operating time for non-transient operation	$(X-\bar{X})$	$(X - \bar{X})^2$
1.	0.70	-0.008	0.000064
2.	0.71	+0.002	0.000004
3.	0.70	-0.008	0.000064
4.	0.72	+0.012	0.000144
5.	0.70	-0.008	0.000064
6.	0.71	+0.002	0.000004
7.	0.73	+0.022	0.000484
8.	0.725	+0.017	0.000289
9.	0.71	+0.002	0.000004
10.	0.705	-0.003	0.000009
11.	0.70	-0.008	0.000064
12.	0.70	-0.008	0.000064
13.	0.70	-0.008	0.000064
	9.21		0.00132

Arithmetic Mean $= \bar{X} = \frac{9.21}{13}$

$= 0.708$

Standard deviation

$$= \sigma = \sqrt{\frac{(X - \bar{X})^2}{N}}$$

$$= \sqrt{\frac{0.00132}{13}}$$

$$= \sqrt{0.0001017}$$

$$= 0.01008$$

TABLE - VII

CALCULATION OF STANDARD DEVIATION.

Sl. No.	Operating time for transient operation.	$(x - \bar{x})$	$(x - \bar{x})^2$	Sl. No.	Operating time for non-tran. operation.	$(X - \bar{X})$	$(X - \bar{X})^2$
1.	0.35 sec.	+0.01	0.0001	1.	0.43 sec	0.0005	0.00000025
2.	0.36 ,,	+0.02	0.0004	2.	0.425	0.0045	0.00002025
3.	0.35 ,,	-0.01	0.0001	3.	0.43	0.0005	0.00000025
4.	0.33 ,,	-0.01	0.0001	4.	0.435	0.0055	0.00003025
5.	0.36 ,,	+0.02	0.0004	5.	0.42	0.0095	0.00009025
6.	0.36 ,,	+0.02	0.0004	6.	0.43	0.005	0.00000025
7.	0.38 ,,	+0.04	0.0016	7.	0.425	0.0045	0.00002025
8.	0.32 ,,	-0.02	0.0004	8.	0.44	0.0105	0.00011025
9.	0.37 ,,	+0.05	0.0025	9.	0.44	0.0105	0.00011025
10.	0.32 ,,	-0.02	0.0004	10.	0.42	0.0095	0.00009025
					0.4295		0.0004725
11.	0.35 ,,	+0.01	0.001				
12.	0.35 ,,	-0.01	0.0001				
13.	0.33 ,,	-0.01	0.0001				
14.	0.30 ,,	-0.04	0.0006				
15.	0.31 ,,	-0.03	0.0009				
	5.10		0.0095				

Arithmetic Mean $= \bar{X} = \frac{5.10}{15} = 0.34$

Standard deviation

$$= \sqrt{\frac{(x - \bar{x})^2}{N}}$$

$$= \sqrt{\frac{0.0095}{15}}$$

$$= 0.0251$$

Arithmetic Mean $= \bar{X} = \frac{04.295}{10}$

Standard deviation

$$= \sqrt{\frac{(x - \bar{x})^2}{N}}$$

$$= \sqrt{\frac{0.0004725}{10.}}$$

$$= \sqrt{0.00004725}$$

$$= 0.00687$$

TABLE - VIII A

Sl. No.	& Positive peaks of transient	Frequency of occurance	Cumulative frequence
1.	187.5	1	1
2.	185.5	1	2
3.	184.6	1	3
4.	183.3	2	5
5.	180.0	1	6
6.	178.5	3	9
7.	178	1	10
8.	175.6	1	11
9.	175	2	13
10.	174.3	4	17
11.	172	1	18
12.	170	1	19
13.	166.7	1	20
14.	163	1	21
15.	158	1	22
16.	128	1	23

T A B L E - VIII B.

Sl. No.	Nagative peaks of transient	Frequency of occurance	comulative frequency.
1.	185.7	1	1
2.	180.0	1	2
3.	177.4	2	4
4.	176.9	1	5
5.	175	7	12
6.	174.3	9	21
7.	169.5	1	22
8.	166.6	2	24
9.	165	2	26
10.	164.3	3	29
11.	163.5	1	30
12.	162	1	31
13.	157	1	32
14.	156.4	1	33
15.	155.2	1	34
16.	140	1	35
17.	135	1	36

T A B L E - IX

1. From the photograph the peak is 1.756 times the normal peak, therefore we have

$$2 \sin(\theta - \lambda) = 1.756$$

$$\sin(\theta - \lambda) = 0.878 = \sin 61.4$$

$$\therefore \theta - \lambda = 61.4$$

$$\therefore \lambda = \theta - 61.4 = 87.25 - 61.40$$

$$\therefore \lambda = \underline{25.85^\circ}$$

2. From the photograph the peak is 1.564 times the normal therefore we have

$$2 \sin(\theta - \lambda) = 1.564$$

$$\sin(\theta - \lambda) = 0.782 = \sin 51.5$$

$$\therefore \theta - \lambda = 51.5$$

$$\therefore \lambda = \theta - 51.5 = 87.25 - 51.50$$

$$\therefore \lambda = \underline{35.75^\circ}$$

3. From the photograph the peak is 1.281 times the normal peak, therefore we have

$$2 \sin(\theta - \lambda) = 1.281$$

$$\sin(\theta - \lambda) = 0.6405 = \sin 39.8$$

$$\therefore \lambda = \underline{47.45^\circ}$$

4. From the photograph the peak is 1.552 times the normal pėak, therefore we have

$$2 \sin(\theta - \lambda) = 1.552$$

$$\therefore \sin(\theta - \lambda) = 0.776 = \sin 50.9^\circ$$

$$\therefore \theta - \lambda = 50.0^\circ$$

$$\therefore \lambda = 87.25 - 50.9 = \underline{36.35^\circ}$$

5. From the photograph the peak is 1.667 times the normal peak, therefore we have

$$2 \sin(\theta - \lambda) = 1.667$$

$$\text{But} \quad \theta = \tan^{-1}\frac{wl}{R} = \tan^{-1}\frac{(314)(126.6)\times10^{-3}}{1.902}$$

$$= \tan^{-1} 20.9$$

$$= 87.25°$$

$$\sin(\theta - \lambda) = 0.8335 = \sin 56.5°$$

$$\therefore \theta - \lambda = 56.5°$$

$$\therefore \lambda = \theta - 56.5 = 87.25 - 56.5°$$

$$\therefore \lambda = 30.75°$$

6. From the photograph the peak is 1.693 times the normal peak, therefore we have

$$2 \sin(\theta - \lambda) = 1.693$$

$$\sin(\theta - \lambda) = 0.846 = \sin 57.8$$

$$= 87.25 - 57.80 = 29.45$$

7. From the photograph the peak is 1.630 times the normal peak, therefore we have

$$2 \sin(\theta - \lambda) = 1.630$$

$$\sin(\theta - \lambda) = 0.815 = \sin 54.6$$

$$\therefore \theta - \lambda = 54.6$$

$$\therefore \lambda = 87.25 - 54.6 = 32.65°$$

8. From the photograph the peak is 1.644 times the normal peak, therefore we have

$$2 \sin(\theta - \lambda) = 1.644 \quad \therefore \sin(\theta - \lambda) = 0.822$$

$$= \sin 55.3° \quad \therefore \theta - \lambda = 55.3$$

$$\therefore \lambda = 87.25 - 55.3 = 31.95°$$

TABLE - X

1. From the photograph the peak is 1.635 times the normal peak

$$2 \sin(\theta - \lambda) = 1.635$$

$$\sin(\theta - \lambda) = 0.8175 = \sin 54.8°$$

$$\therefore \theta - \lambda = 54.8°$$

But $\theta = \tan^{-1}\frac{wl}{R} = \tan^{-1}\frac{(314)(100.34) \times 10^{-3}}{1.719}$

$$= \tan^{-1} 12.51 = 85.45°$$

$$\theta = 85.45°$$

Since $\theta - \lambda = 54.8$ ~~xx85x45xxx94x8~~

$$\therefore \lambda = \theta - 54.8 = 85.45 - 54.8$$

$$\therefore \lambda = \underline{30.65°}$$

2. From the photograph the peak is 1.743 times the normal peak

$$2 \sin(\theta - \lambda) = 1.743$$

$$\sin(\theta - \lambda) = 0.8715 = \sin 60.6$$

$$\theta - \lambda = 60.6°$$

~~=x0xxxxxxx60x6x~~

$$\therefore \lambda = 85.45 - 60.6 = 24.85°$$

3. From the photograph the peak is 1.743 times the normal peak

$$2 \sin(\theta - \lambda) = 1.743$$

$$\sin(\theta - \lambda) = 0.8715 = \sin. 60.6$$

$$\therefore \theta - \lambda = 60.6$$

$$\therefore \lambda = 85.45 - 60.6 = 24.85°$$

4. -do- $\lambda = 24.85°$

5. -do- $\lambda = 24.85°$

6. From the photograph the peak is 1.857 times the normal peak

$$2 \sin (\theta - \lambda) = 1.857$$

$$\sin (\theta - \lambda) = 0.9285 = \sin 68.2^\circ$$

$$\theta - \lambda = 68.2^\circ$$

$$\therefore \lambda = 85.45^\circ - 68.2^\circ = 17.25^\circ$$

7. From the photograph the peak is 1.743 times the normal peak

$$2 \sin (\theta - \lambda) = 1.743$$

$$\sin (\theta - \lambda) = 0.8715 = \sin 60.6$$

$$\therefore \theta - \lambda = 60.6^\circ$$

$$\therefore \lambda = 85.45 - 60.6 = 24.85^\circ$$

8. From the photograph the peak is 1.743 times the normal peak.

$$2 \sin (\theta - \lambda) = 1.743$$

$$\sin (\theta - \lambda) = 0.8715 = \sin 60.6^\circ$$

$$\theta - \lambda = 60.6^\circ$$

$$\therefore \lambda = \theta - 60.6 = 85.45 - 60.6^\circ$$

$$= 24.85$$

9. -do- $\therefore \lambda = 24.85^\circ$

10. -do- $\therefore \lambda = 24.85^\circ$

TABLE - XI

1. From the photograph the peak is 1.785 times the normal peak.

$$2 \sin (\theta - \lambda) = 1.785$$
$$\sin (\theta - \lambda) = 0.8925 = \sin 63.2°$$
$$\theta - \lambda = 63.2°$$
$$\therefore \lambda = 87.25 - 63.2° = 24.25°$$

Since $\theta = \tan^{-1} \frac{wl}{R} = \tan^{-1} \frac{(314)\ (126.6) x 10^{-3}}{1.902}$

$$= \tan^{-1} \frac{(39752.4)\ (10^{-3})}{1.902} = \tan^{-1} 20.9 = 87.25°$$

2. From the photograph the peak is 1.846 times the normal peak

$$2 \sin (\theta - \lambda) = 1.846$$
$$\sin (\theta - \lambda) = 0.923 = \sin 67.4°$$
$$\theta - \lambda = 67.4°$$
$$= \theta - 67.4 = 87.25 - 67.4$$
$$\therefore \lambda = 19.85°$$

3. From the photograph the peak is 1.740 times the normal peak

$$2 \sin (\theta - \lambda) = 1.740$$
$$\sin (\theta - \lambda) = 0.870 = \sin 60.4°$$
$$\theta - \lambda = 60.4°$$
$$\therefore \lambda = \theta - 60.4 = 87.25 - 60.4$$
$$= \underline{26.85°}$$

4. From the photograph the peak is 1.785 times the normal peak

$$2 \sin (\theta - \lambda) = 1.785 \quad \therefore \sin (\theta - \lambda) = 0.8925 = \sin 63.2°$$
$$\theta - \lambda = 63.2°$$
$$\therefore \lambda = \theta - 63.2 = 87.25° - 63.2°$$
$$= 24.05°$$

5. From the photograph the peak is 1.742 times the normal peak.

$$2 \sin(\theta - \lambda) = 1.742$$

$$\sin(\theta - \lambda) = 0.871 = \sin 60.6°$$

$$\theta - \lambda = 60.6$$

$$\therefore \quad \lambda = 87.25 - 60.6 = 26.65°$$

6. From the photograph the peak is 1.785 times the normal peak

$$2 \sin(\theta - \lambda) = 1.785$$

$$\sin(\theta - \lambda) = 0.8925 = \sin 63.2°$$

$$\theta - \lambda = 63.2°$$

$$\therefore \quad \lambda = 87.25 - 63.2 = 24.05°$$

7. From the photograph the peak is 1.769 times the normal peak

$$2 \sin(\theta - \lambda) = 1.769$$

$$\sin(\theta - \lambda) = 0.8845 = \sin 61.7°$$

$$\therefore \theta - \lambda = 61.7°$$

$$\therefore \quad \lambda = 87.25 - 61.70 = 25.55°$$

8. From the photograph the peak is 1.742

$$2 \sin(\theta - \lambda) = 1.742$$

$$\sin(\theta - \lambda) = 0.871 = \sin 60.6°$$

$$\therefore \theta - \lambda = 60.6°$$

$$\therefore \quad \lambda = \theta - 60.6 = 87.25 - 60.6°$$

$$\therefore \lambda = 26.65°$$

9. -do- $\lambda = 26.65°$

10. From the photograph the peak is 1.666 times the normal peak

$$2 \sin(\theta - \lambda) = 1.666 \quad \sin(\theta - \lambda) = 0.833$$

$$\theta - \lambda = 56.45° \quad = \sin 56.45°$$

$$\therefore \quad \lambda = 87.25 - 56.45° = 30.80°$$

TABLE -XII

1. From the photograph the peak is 1.777 times the normal peak

$$2 \sin (\theta - \lambda) = 1.777$$

$$\sin (\theta - \lambda) = 0.8885 = \sin 62.7°$$

$$\theta - \lambda = 62.7°$$

$$\text{Since } \theta = \tan^{-1}\frac{wl}{R} = \tan^{-1}\frac{(314)\ (100.34) \times 10^{-3}}{1.719}$$

$$= \tan^{-1}\frac{31.50676}{1.719} = \tan^{-1} 18.33 = 86.9°$$

$$\theta - \lambda = 62.7°$$

$$\therefore \quad \lambda = 86.9 - 62.7° = 24.2°$$

2. From the photograph the peak is 1.580 times the normal peak.

$$2 \sin (\theta - \lambda) = 1.580$$

$$\sin (\theta - \lambda) = 0.790 = \sin 52.20$$

$$\theta - \lambda = 52.2°$$

$$\therefore \quad \lambda = 86.9 - 52.2 = 34.7°$$

3. From the photograph the peak is 1.875 times the normal peak

$$2 \sin (\theta - \lambda) = 1.875$$

$$\sin (\theta - \lambda) = 0.9375 = \sin 69.6°$$

$$\therefore \theta - \lambda = 69.6°$$

$$\therefore \lambda = 86.9 - 69.6 = 17.3°$$

4. From the photograph the peak is 1.777 times the normal peak

$$2 \sin (\theta - \lambda) = 1.777; \ \sin (\theta - \lambda) = 0.8885 = \sin 62.7°$$

$$\therefore \theta - \lambda = 62.7°$$

$$\therefore \quad \lambda = \theta - 62.7 = 86.9 - 62.7 = 24.2°$$

TABLE- XIII

1. From the photograph the peak is 1.571 times the normal peak.

$$2 \sin (\theta - \lambda) = 1.571$$

$$\sin (\theta - \lambda) = 0.7855 = \sin 51.8°$$

$$\theta - \lambda = 51.8°$$

$$\therefore \lambda = 87.9 - 51.8 = 36.1$$

2. From the photograph the peak is 1.643 times the normal peak.

$$2 \sin (\theta - \lambda) = 1.643; \quad \sin (\theta - \lambda) = 0.8215 = \sin 55.2°$$

$$\theta - \lambda = 55.2$$

$$\therefore \lambda = \theta - 55.2 = 87.9 - 55.2 = 32.7°$$

3. From the photograph the peak is 1.855 times the normal peak

$$2 \sin (\theta - \lambda) = 1.855$$

$$\sin (\theta - \lambda) = 0.9275 = \sin 68.1$$

$$\theta - \lambda = 68.1°$$

$$\therefore \lambda = 87.9 - 68.1 = 19.8°$$

4. From the photograph the peak is 1.785 times the normal peak.

$$2 \sin (\theta - \lambda) = 1.785$$

$$\sin (\theta - \lambda) = 0.8925 = \sin 63.2°$$

$$\theta - \lambda = 63.2$$

$$\therefore \lambda = 87.9 - 63.2 = 24.7°$$

TABLE -XIV

1. From the photograph the peak is 1.751 times the normal peak.

$$2 \sin (\theta - \lambda) = 1.751$$

$$\sin (\theta - \lambda) = 0.875 = \sin 61.1°$$

$$\theta - \lambda = 61.1°$$

$$\therefore \lambda = 87.2 - 61.1 = 26.1°$$

$$\text{Since } \theta = \tan^{-1} \frac{wl}{R} = \tan^{-1} \frac{(314)(70.93)(10)^{-3}}{1.0865}$$

$$= \tan^{-1} \frac{22.27202}{1.0865} = \tan^{-1} 20.5 = 87.2°$$

2. From the photograph the peak is 1.666 times the normal peak.

$$2 \sin (\theta - \lambda) = 1.666$$

$$\sin (\theta - \lambda) = 0.833 = \sin 56.4°$$

$$\therefore \theta - \lambda = 56.4$$

$$\therefore \lambda = 87.2 - 56.4 = 30.8°$$

3. From the photograph the peak is 1.751 times the normal peak.

$$2 \sin (\theta - \lambda) = 1.751$$

$$\sin (\theta - \lambda) = 0.875 = \sin 61.1°$$

$$\therefore \lambda = 87.2 - 61.1 = 26.1°$$

4. From the photograph the peak is 1.751 times the normal peak.

$$2 \sin (\theta - \lambda) = 1.751$$

$$\sin (\theta - \lambda) = 0.875 = \sin 61.1°$$

$$\theta - \lambda = 61.1°$$

$$\therefore \lambda = 87.2 - 61.1 = 26.1°$$

XIV

5. From the photograph the peak is 1.833 times the normal peak.

$$2 \sin(\theta - \lambda) = 1.833$$

$$\sin(\theta - \lambda) = 0.9165 = \sin 66.4°$$

$$\therefore \theta - \lambda = 66.4°$$

$$\therefore \lambda = 87.2 - 66.4° = 20.8°$$

6. From the photograph the peak is 1.751 times the normal peak

$$2 \sin(\theta - \lambda) = 1.751$$

$$\sin(\theta - \lambda) = 0.875 = \sin 61.1°$$

$$\theta - \lambda = 61.1°$$

$$\therefore \lambda = 87.2 - 61.1 = 26.1$$

7. From the photograph the peak is 1.833 times the normal peak.

$$2 \sin(\theta - \lambda) = 1.833$$

$$\sin(\theta - \lambda) = 0.9165 = \sin 66.4°$$

$$\therefore \theta - \lambda = 66.4°$$

$$\therefore \lambda = 87.2 - 66.4 = 20.8°$$

8. From the photograph the peak is 1.751 times the normal peak.

$$2 \sin(\theta - \lambda) = 1.751$$

$$\sin(\theta - \lambda) = 0.875 = \sin 61.1°$$

$$\therefore \theta - \lambda = 61.1$$

$$\therefore \lambda = 87.2 - 61.1 = 26.1°$$

T A B L E - XV

1. From the photograph the peak is 1.650 times the normal peak

$$2 \sin(\theta - \lambda) = 1.650$$

$$\sin(\theta - \lambda) = 0.825 = \sin 55.6°$$

$$\theta - \lambda = 55.6°$$

$$\theta = \tan^{-1} \frac{wl}{R} = \tan^{-1} \frac{(314)(103.13)10^{-3}}{1.280}$$

$$= \tan^{-1} \frac{32.3828}{1.280} = \tan^{-1} 25.457 = 87.75°$$

$$\therefore \quad \lambda = \theta - 55.6$$

$$= 87.75 - 55.60 = \underline{32.15}°$$

2. From the photograph the peak is 1.720 times the normal peak

$$2 \sin(\theta - \lambda) = 1.720$$

$$\sin(\theta - \lambda) = 0.860 = \sin 59.4°$$

$$\theta - \lambda = 59.4°$$

$$\therefore \quad \lambda = 87.75 - 59.4 = 28.35°$$

3. From the photograph the peak is 1.620 times the normal peak

$$2 \sin(\theta - \lambda) = 1.620$$

$$\sin(\theta - \lambda) = 0.810 = \sin 54.1$$

$$\theta - \lambda = 54.1°$$

$$\therefore \quad \lambda = 87.75 - 54.1 = 33.65°$$

4. From the photograph the peak is 1.350 times the normal peak.

$$2 \sin(\theta - \lambda) = 1.350$$

$$\sin(\theta - \lambda) = 0.675 = \sin 42.5°$$

$$\theta - \lambda = 42.5°$$

$$\therefore \quad \lambda = 87.75 - 42.50 = 45.25°$$

XV

5. From the photograph the peaks is 1.750 times the normal peak.

$$2 \text{ Sin } (\theta - \lambda) = 1.750$$

$$\text{Sin } (\theta - \lambda) = 0.875 = \text{Sin } 61.1°$$

$$\theta - \lambda = 61.1°$$

$$\therefore \quad \lambda = 87.75 - 61.1 = 26.65°$$

6. From the photograph the peak is 1.400 times the normal peak.

$$2 \text{ Sin } (\theta - \lambda) = 1.400$$

$$\text{Sin}(\theta - \lambda) = 0.700 = \text{Sin } 44.5°$$

$$\theta - \lambda = 44.5°$$

$$\therefore \quad \lambda = 87.75 - 44.50 = 43.25°$$

7. From the photograph the peak is 1.750 times the normal peak.

$$2 \text{ Sin } (\theta - \lambda) = 1.7500$$

$$\text{Sin } (\theta - \lambda) = 0.875 = \text{Sin } 61.1°$$

$$\theta - \lambda = 61.1$$

$$\therefore \quad \lambda = 87.75 - 61.10 = 26.65°$$

8. From the photograph the peak is 1.750 times the normal peak.

$$2 \text{ Sin } (\theta - \lambda) = 1.750$$

$$\text{Sin } (\theta - \lambda) = 0.875 = \text{Sin } 61.1°$$

$$\therefore \theta - \lambda = 61.1°$$

$$\therefore \lambda = 87.75 - 61.1° = 26.65°$$

9. From the photograph the peak is 1.650 times the normal peak.

$$2 \sin(\theta - \lambda) = 1.650$$

$$(\theta - \lambda) = 0.825 = \sin 55.6°$$

$$\theta - \lambda = 55.6°$$

$$\therefore \lambda = 87.75 - 55.6 = 32.15°$$

10. From the photograph the peak is 1.700 times the normal peak.

$$2 \sin(\theta - \lambda) = 1.700$$

$$\sin(\theta - \lambda) = 0.850 = \sin 58.2°$$

$$\theta - \lambda = 58.2°$$

$$\therefore \lambda = 87.75 - 58.2 = 29.55°$$

11. From the photograph the peak is 1.800 times the normal peak

$$2 \sin(\theta - \lambda) = 1.800$$

$$\sin(\theta - \lambda) = 0.900 = \sin 64.2°$$

$$\therefore \theta - \lambda = 64.2°$$

$$\therefore \lambda = \theta - 64.2 = 87.75 - 64.2$$

$$= 23.55°$$

12. From the photograph the peak is 1.780 times the normal peak.

$$2 \sin(\theta - \lambda) = 1.780$$

$$\sin(\theta - \lambda) = 0.890 = \sin 62.9°$$

$$\theta - \lambda = 62.9°$$

$$\therefore \lambda = 87.75 - 62.9 = \underline{25.85°}$$

TABLE - XVI

Sl.No.	Non-transient relay operating times in sec.	Transient relay operating time in sec.	Reduction of operating time in percentage
1.	0.930	0.865	6.98%
2.	0.682	0.626	6.34%
3.	1.071	0.880	17.8%
4.	1.973	1.900	3.6%
5.	1.529	1.433	6.2%
6.	0.708	0.650	8.2%
7.	0.4295	0.340	20.8%