APPLICATION OF HIPERNIK REACTORS TO FREQUENCY SHIFT KEYING AT 100 KILOCYCLES PER SECOND

BY

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PREFACE

This thesis is the result of work accomplished at the Westinghouse Electric Corporation, Wilkens Avenue, Baltimore, Maryland. The general aim of the project was to ascertain the feasibility of frequency shift keying an oscillator by means of Hipernik reactors at a frequency of 100 kilicycles per second. The work was performed during the first quarter of 1951 under the general supervision of Mr. Mark Jacob, Section Engineer in charge of Communications, Government Engineering Division, Westinghouse Electric Corporation. Mr. Jacob and engineers in his section, particularly Messrs. Henry Musk, Orville Hall and Arnold Veiner were of invaluable aid. They were ready at all times to listen to the problems which arose and to offer suggestions and leads. Mr. John Evans of the Feeder Engineering Group was also helpful. His experience with reactors was of great assistance in perusing this project.

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INTRODUCTION

It has been said that a great shame of the nineteenth century was its ignorance of magnetic phenomena. The great revival of interest in ferromagnetism is obvious to the most casual reader of contemporary technical literature. The application of reactors has and is continuing to increase many fold. Appendix A is only a partial list of their applications yet it contains twenty two items. That many more will be added is a foregone conclusion; indeed this paper describes an application which after further refinement might well be added.

There are of course many reasons for the strides which have been made in the field of ferromagnetism. One reason which may be overlooked but was made very obvious to the writer in persuing this investigation was the improvement in measuring equipment in the last two decades. Improved measuring techniques which have been translated into useful laboratory tools make possible the precise measurements which an investigator must make if he is to learn much about his project. It is almost certain that the measurements of precise frequency made during the course of this investigation at Westinghouse Corporation and at the Postgraduate School would not have been made many years ago because the equipment used has until recently been available only at standards laboratories. It is not enough to have the equipment available at a few widely scattered locations; it must be available to investigators wherever they may be.

It must be available to the humble students working on their theses. Another rather prosaic instrument these days is the vacuum tube voltmeter. They are found in some quantity in almost any electronics laboratory. What a surprising sight it would have been twenty years ago to see an investigator using three such instruments on one experiment. Yet this investigator could and did use such instruments without depriving his fellows. It is axiomatic that the more people who are engaged in such investigations, the more we are likely to find out. The ability to make fine measurements reveals properties which an engineer may turn into a useful application. So with iron, more is being learned every day and more applications will be added to the list. There is considerable promise that ignorance of magnetic phenomena will not be "a shame of the twentieth century."

The application of an iron core reactor for frequency control is a very fundamental one. It is a well exploited principle that the inductance of a circuit is not constant if any material of variable permeability is within the magnetic field of the circuit. In fact, the reactance of such a circuit is directly proportional to the permeability. An iron core reactor certainly has a variable permeability. It is also a well known and frequently used principle that the inductance of a coil wound on an iron core is function of both the direct and alternating current flowing through the coil. A more precise way of stating the above is that the inductance is a function of the flux caused by the

direct and alternating current. Throughout this paper when reference is made to DC flux and AC flux it is to be understood that the flux is that set up by the current in the coil. Whether the flux is induced by current through a given coil or by current through another coil on the same core, is a matter only of degree. Thus, considering a toroid, it is possible to change the inductance of one winding by changing direct current flowing through another winding. If this inductance is part of a tuned circuit we can change the frequency of the circuit. If this tuned circuit is the frequency controlling element of an oscillator and if we can shift the frequency fast enough we have frequency shift keying. How precisely, how rapidly and how conveniently the frequency can be shifted was the subject of investigation reported in this paper.

It was learned that the frequency of a 100 kc oscillator could be shifted quite conveniently by 1000 cycles per second. The shift could be made very precisely. The problem of making this shift rapidly has not been completely solved. A considerable amount of work has been done on this problem in connection with magnetic amplifiers. Such information is directly applicable to this application. See Harder (19), Johnson (25). On-off keying speeds up to 200 words per minute are within the capabilities of the circuit used. There is considerable promise that this can be increased. There is an hysteresis effect noted in using reactors which results in a frequency deviation. Whether or

not this is a prohibitive problem depends on the frequency accuracy required. It is doubtful if in frequency shift keying at 100 kc that this effect will be prohibitive, provided of course that realistic requirements are set forth.

CHAPTER I

ANALYSIS OF PROBLEM

The remarks set forth in the introduction indicate that frequency shift keying is indeed possible. The specific problem was to ascertain if it were practicable with Hipernik V toroids and to determine limitations of the method at 100 kc. The frequencies at which there is considerable knowledge of Hipernik V, and this applies to most iron, are 60 and 400 cycles per second. Little use has been made of iron core components beyond the audio range. There is available some experience but not much data on iron cores at 18kc. Powdered iron cores have some attractive advantages for such an application as this but they generally require greater current or greater ampere turns to accomplish the same amount of frequency shift.

As a general goal it was attempted to shift a 100 kc oscillator by 1,000 cps with an accuracy of plus or minus one cycle per second. The amount of current required to accomplish the shift should be that available from a single receiving type tube. To that end most of the data recorded has been gathered with direct currents of the order of 100 milliamperes.

The use of toroids in place of reactance tubes would be most attractive if they could reduce the actual number of tubes in the circuit. If power stages are required to supply large amounts of direct current one advantage has been lost. Of course one real advantage would remain. The life of a

piece of magnetic iron has not been determined, yet it is undoubtedly longer than the combined life of a bushel of tubes.

The frequency response versus control current curve should be such that the ratio of the slope of a line joining any two points on the curve to the slope of a line joining the end points of the curve should be not greater than 1.1/1. This criterion was made on the basis of certain military specifications in which it is a requirement.

CHAPTER II

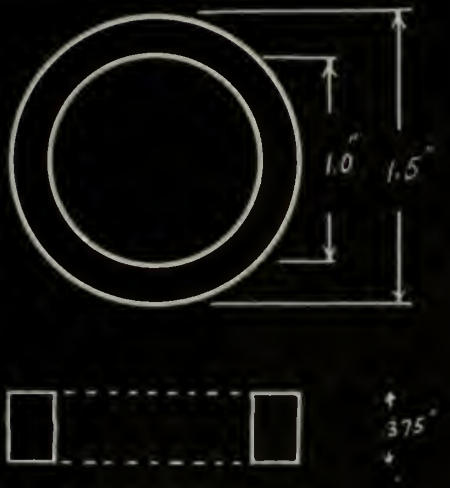
THE TOROIDS

1. Physical Considerations

To take full advantage of the high permeability of a nickel iron alloy a gapless type of construction is indicated. It is fairly common engineering knowledge that with a magnetic material having a maximum permeability of 100,000 an air gap of .001 inches in the magnetic path reduces the effective permeability to less than 5,000. Gapless construction results in minimum leakage and maximum effective permeability. It is usual to make use of stamped laminations where lamination thickness is 5 mils or larger; however stamping and annealing of thinner laminations is impracticable. The cores used in this investigation were continuously wound of 2 mil Hipernik V. This type of construction is often described as clockspring or centricore or more sensibly as continuous ~~tape~~ tape wound. Dimensions and other physical characteristics are given on Figure 1 page 8. It is commerical practice, as was done in this case, to protect the cores by encasing them in a plastic container. This is necessary because the cores are very susceptible to deformation and such deformation during winding or subsequent handling results in deterioration of the magnetic properties.

The toroidal form of core has met with some unpopularity in the past, in spite of its advantages, because of the ingenuity and patience required to perform the winding operation; however, universal toroidal winding machines are now

TOROID DETAILS



CORE MATERIAL : HIPERNIK V
.002" THICK
MEAN LENGTH : 3.93"
WINDINGS :

1-3	100 TURNS	NO. 32	CU.
7-8	200 "	" 28	CU.
9-10	100 "	" 28	CU.

Figure 1, Page 8

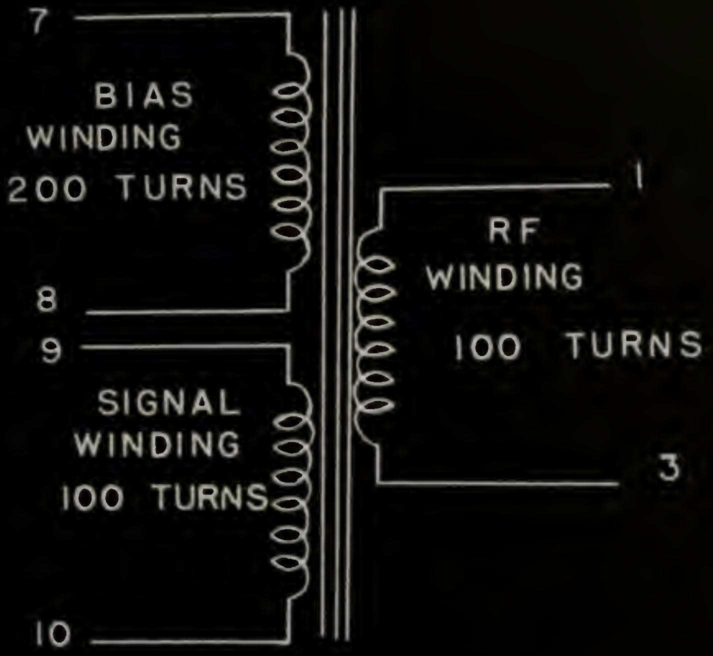
available and have overcome some of the objections.

The thickness of the foil is one parameter which has considerable effect on the eddy current losses in a reactor. Such losses are proportional to the square of the thickness. Although magnetic tape foils are available in one mil thickness the material used in the toroids described herein was two mils thick. It is the belief of this investigator that any future investigation along this line should employ the thinnest foil that is commercially available. Quartering the eddy current losses, which turned out to be the only important source of loss, should result in a more satisfactory component.

The physical size of the core may also be reduced somewhat, thereby reducing core losses; however it is doubtful if a much smaller core could have been used. After the toroid has been encased in its plastic container, the windings put on and the latter protected by a tape covering, there was very little space in the center.

2. Electrical Measurements on Toroids

The winding arrangment is shown on Figure 2 page 10. The rf windings may be connected in series or parallel. In order to get maximum inductance the series connection was chosen. It also happens that for shorter response time, which is taken up in chapter IV in more detail, the series connection is better. The control and bias windings were connected differentially, i.e., they were connected in series bucking with terminal 8 of one toroid connected to terminal 8 of the second toroid. Similarly terminal 10 of one toroid was connected to terminal 10



TOROID WINDING ARRANGMENT

Figure 2, Page 10

of the second toroid. This prevents coupling of the rf and dc windings by a cancellation process. It is common in magnetic amplifier practice to follow the above procedure.

Unless otherwise noted, all measurements were made at 100 kc. Because in the proposed application a high Q inductive element would be required, the first factor measured was the Q of the rf winding. This measurement was made on a Freed Low Frequency Q Meter. The Q, with no signal or bias current flowing was four. This was a poor start; however after applying signal current to the winding 9-10-10-9, the outlook improved considerably. The Q of the rf winding rose rapidly to about 20 when the signal current was increased to 100 milliamperes. This seemed an anomalous effect but has been noted by Pressman (43) in working with powdered cores. He reported a rise in Q from 10 to 135 by increasing ampere turns from zero to five ampere turns. This data was at 200 kilocycles. Anomalous resistance effects have been noted by Griffiths (45) in the centimeter region. This effect seemed an inviting subject for investigation but after discussion with some rather able men in the field of ferromagnetics it was concluded that such an investigation would soon get far beyond the realm of engineering.

It was decided to make some measurements of the apparent series resistance of the rf windings, terminals 1-3-1-3, since this would give an idea as to the order of magnitude of the losses involved and would serve to check the apparent decrease in resistance with increase in dc flux. A General Radio

5160 RF Bridge was used to make the measurements. The curve of apparent series resistance versus frequence of the two rf windings in series is plotted on Figure 3 page 13. The curve shows a square law response indicating that eddy current losses are the chief contributor. It was also noted that with increased dc flux the series resistance decreased. This supported the Q meter readings.

The usual curves which one sees on the performance of ferromagnetic materials are flux density versus magnetic intensity or BH curves.

The electromotive force induced in a coil of N turns may be expressed as:

$$e = -N \frac{d\phi}{dt} 10^{-8} \text{ volts}$$

e is instantaneous volts

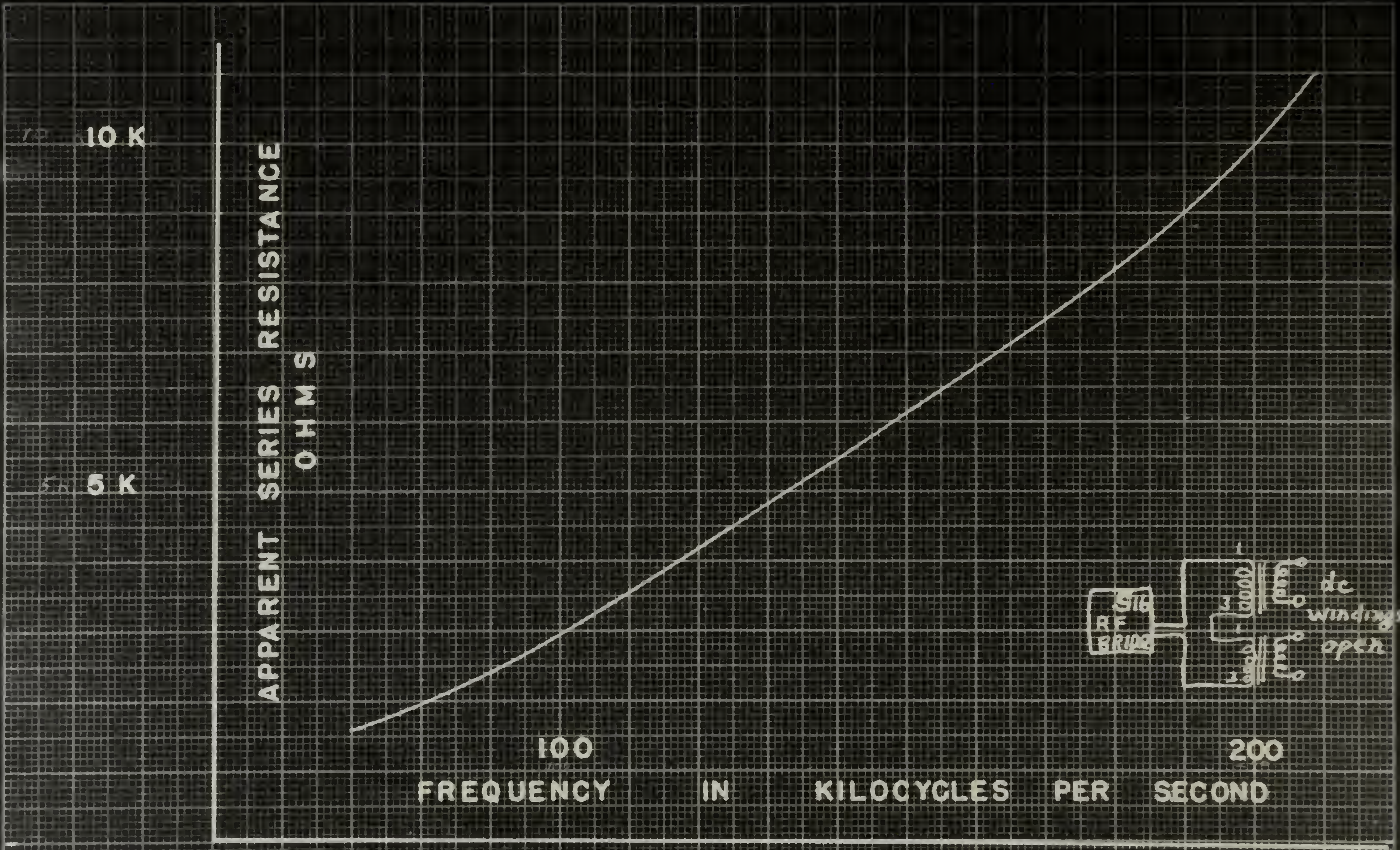
ϕ is flux in maxwells

If the flux is varying sinusoidally

$$\phi = \phi_{max} \sin \omega t$$

$$\frac{d\phi}{dt} = \omega \phi_{max} \cos \omega t$$

The flux density, B, expressed as gausses or maxwells per square



RF WINDING RESISTANCE (GR-516C BRIDGE)

Figure 3, Page 13

centimeter, is by definition:

$$B = \frac{\Phi}{A} \ \frac{\text{maxwells}}{\text{square cm.}}$$

$$B_{max} = \frac{\Phi_{max}}{A}$$

$$\frac{d\Phi}{dt} = A\omega B_{max} \cos \omega t$$

$$e = -NA\omega B_{max} \cos \omega t$$

The maximum absolute value of Voltage, E(max) may be written:

$$E_{max} = NA\omega B_{max} \times 10^{-8} \text{ volts}$$

and

$$B_{RMS} = \frac{E_{RMS}}{NA\omega} 10^{5} \text{ kilogausses}$$

$$B_{RMS} = \frac{1.59}{NAf} E_{RMS} \times 10^{4} \text{ kilogausses}$$

For a given toroid at a particular frequency the coefficient of E(rms) will be a constant. Thus the flux density is proportional to voltage.

Furthermore the expression for the magnetic field intensity within a coil may be written:

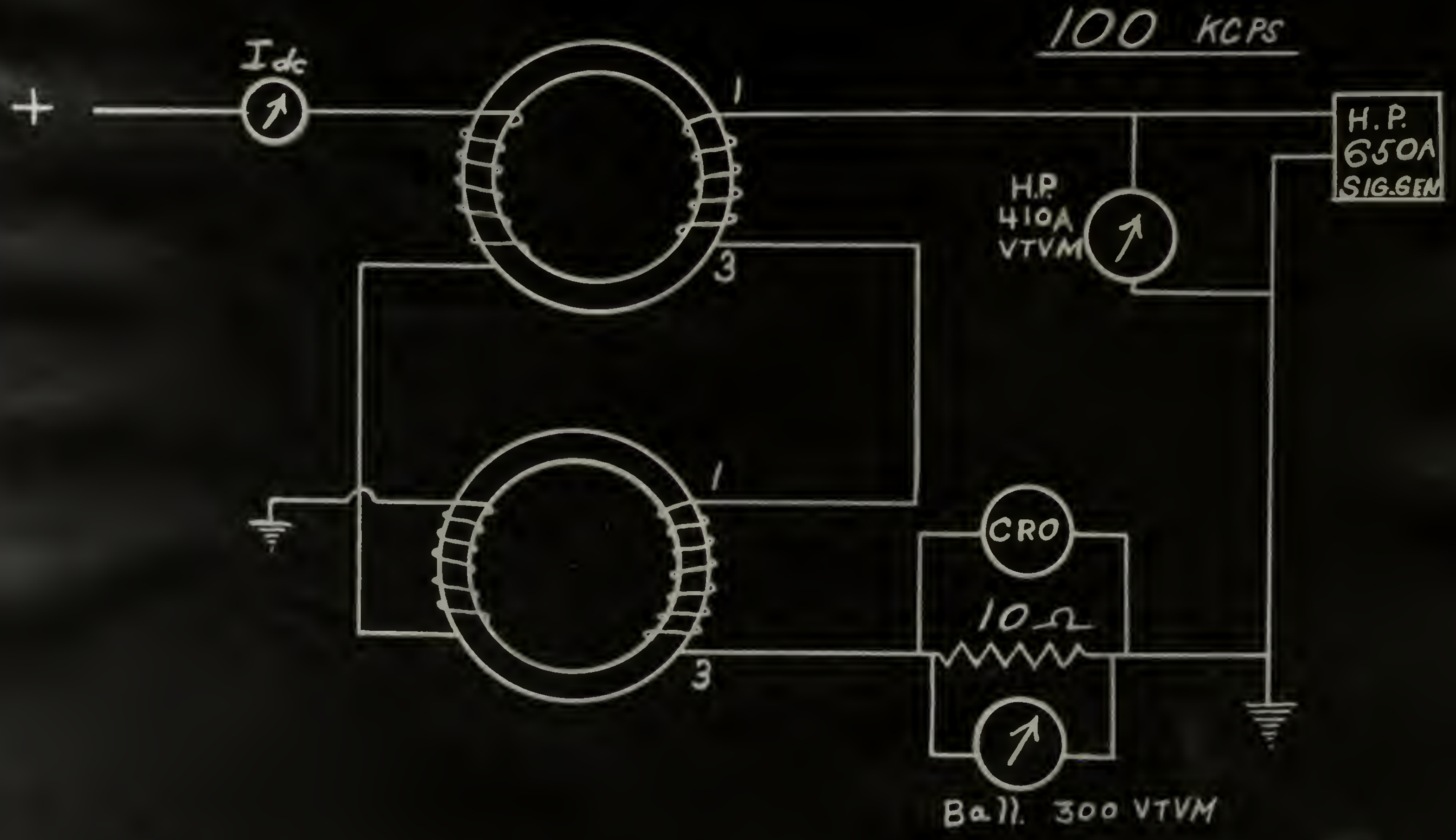
$$H = 0.4\,\pi N I \ \text{lines}/\text{cm}^2$$

I (in amperes)

Thus, for a given toroid at one frequency, the alternating flux density is proportional to applied voltage and magnetic intensity is proportional to the current through the coil. By making measurements of voltage and current in the rf windings, 1-3-1-3, data results which is comparable to and can be converted to BH curves. There seemed to be no need to make the conversion. The Westinghouse Magnetic Amplifier Manual (46) presents similar data as "AC Volts per turn per square ince" versus "Ampere turns per inch". Such a presentation makes the data applicable to any size and winding arrangement whereas a voltage versus current curve is applicable to a given configuration only.

Because there were no known data on Hipernik at 100 kc it was decided to make some precise measurements. The circuit shown as figure 4 page 16 was used. Not shown on the circuit are two amplifiers. One, a Hewlett Packard 450A amplifier was used to increase the output voltage of the HP 650A signal generator, to a maximum of ten volts, the other a Ballentine Amplifier, companion equipment to the Ballentine model 300 VTVM, was used to increase the voltage across the ten ohm resistor. The ten ohm resistor was small enough to have no appreciable effect on the impedance of the circuit. With a low Q, the impedance of the rf winding would be made up of a

Figure 4, Page 16



TYPICAL ARRANGEMENT FOR B-H MEASUREMENT

reactance and a very considerable amount of resistance. Thus at low bias the plot of voltage versus current is no more than an impedance plot. At a bias of five ampere turns, the Q is about ten. At this and higher values of bias the curves can be considered to be proportional to BH curves and conclusions as to permeability can be drawn with some confidence. The zero bias curves should not be considered in drawing conclusions on permeability because of the large resistive component of the impedance.

A cathode ray oscilloscope was used to observe the waveform of voltage. This was done in order to ascertain when the waveform departed from the sinusoidal. The meter readings would have little value if the waveform were complex. All data plotted were taken with sinusoidal waveforms. When the oscilloscope indicated that the distortion ~~was~~ present was above five percent the measurement was not considered valid. In figure 6 page 20 it can be considered that the end points of the bias curves are the points at which serious distortion became apparent. Hysteresis did not manifest itself on the oscilloscope. Hipernik V is considered to have a low hysteresis loss compared to other ferromagnetic materials. That hysteresis did not show up in this way is not surprising; however hysteresis was detected in later experiments and is discussed in Chapter IV.

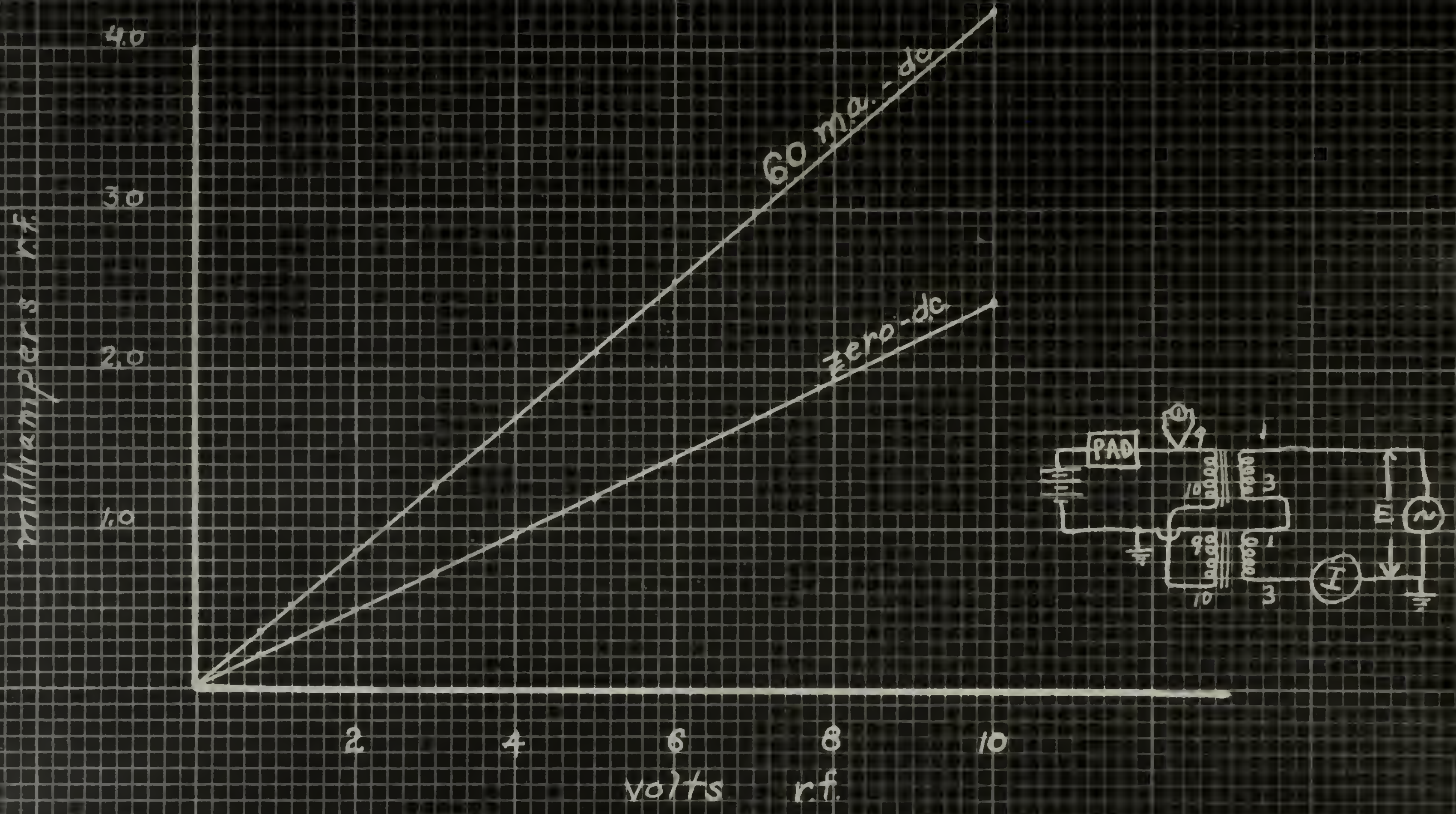
With no dc flowing in the bias or signal winding, the region from zero to one volt ac was investigated. A straight line resulted. With 60 milliamperes flowing in the dc winding

another straight line resulted. This line however had a steeper slope. The region from one to ten volts was investigated with the same results. The data are plotted on figure 5 page 19. This curves shows a linear admittance.

In the usual BH curves one does note this linearity. The linearity is encouraging because it means that when the reactor is used in an oscillator circuit, the ac voltage across the reactor can vary within narrow limits, at least, without changing the reactance of the rf winding. This will permit some freedom in circuit design.

It seemed that it might be interesting and profitable to obtain more complete magnetisation curves for Hipernik. The material saturates at about 15 kilogausses. The formula on page 14 shows that voltages of the order of a few thousand volts are necessary in order to reach a peak saturating flux density with no steady state flux applied, i.e., with no signal or bias. Such magnitudes are not easily obtained in the laboratory. Furthermore, the reactors used in this investigation were designed to withstand only a few hundred volts. This part of the project was reluctantly abandoned. Instead, a power amplifier was constructed which would give something over 125 volts at 100 kilocycles. For the application of the reactors in an oscillator this voltage range is sufficient.

Using a Hewlitt Packard 410A VTVM to observe voltage and a Ballentine 300 VTVM to observe current by taking the voltage across a ten ohm resistor additional data were then taken and are plotted on figure 6 page 20. Over these ranges of voltage



VOLTAGE CURRENT CHARACTERISTIC 100 KC

Figure 5, Page 19

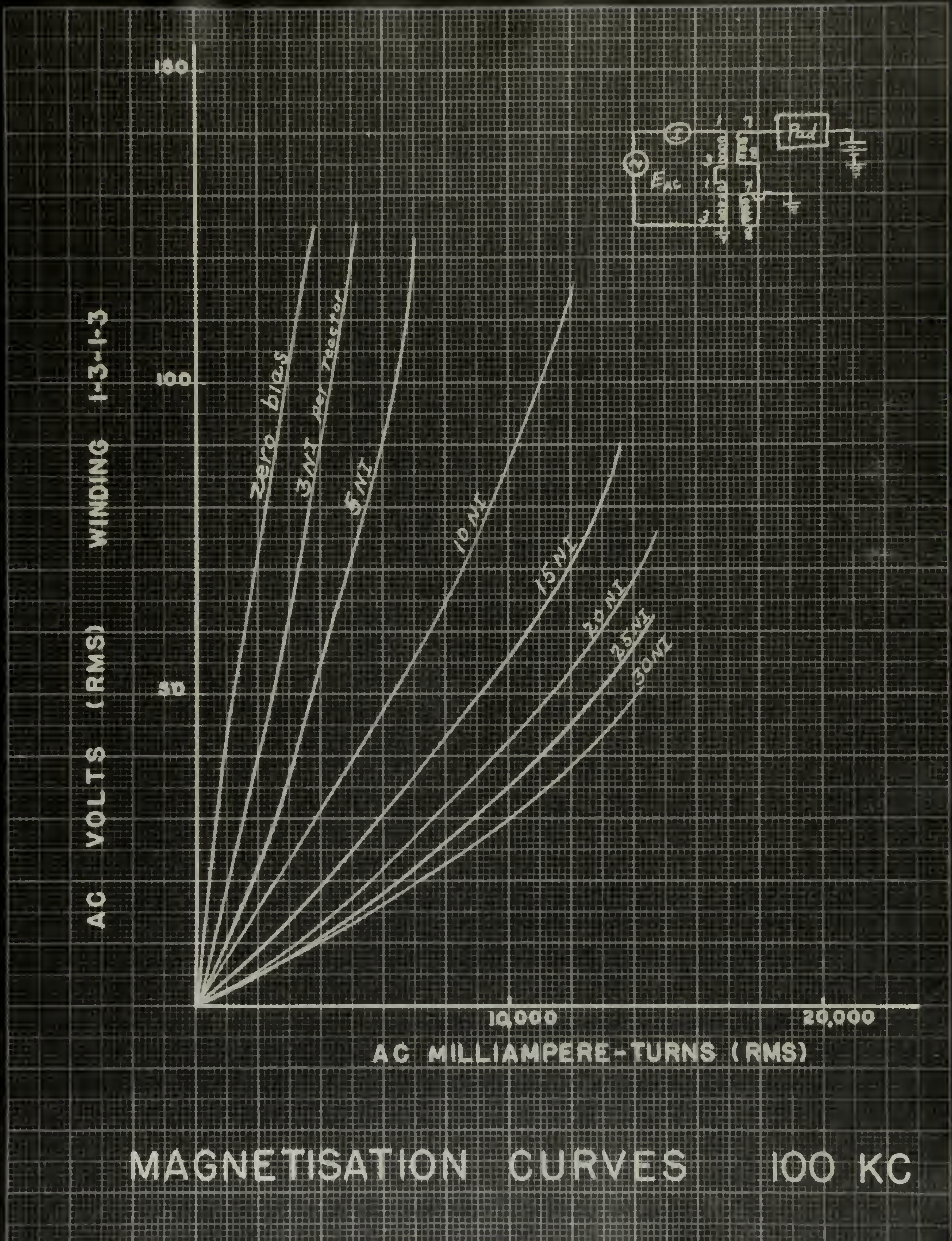


Figure 6, Page 20

it may be noted that the linear relationship is no longer so pronounced; however for any 10 volt range from zero to the maximum, the departure from linearity is slight. Remembering that the reactance of an iron core coil with no air gap is directly proportional to permeability (44) and that the permeability is proportional to the ratio of voltage to current, these curves show that great changes of reactance can be achieved. Taking as an operating locus the 50 volt ac line, there is a ten to one change in permeability when the control NI is raised from 5 to 30 NI.

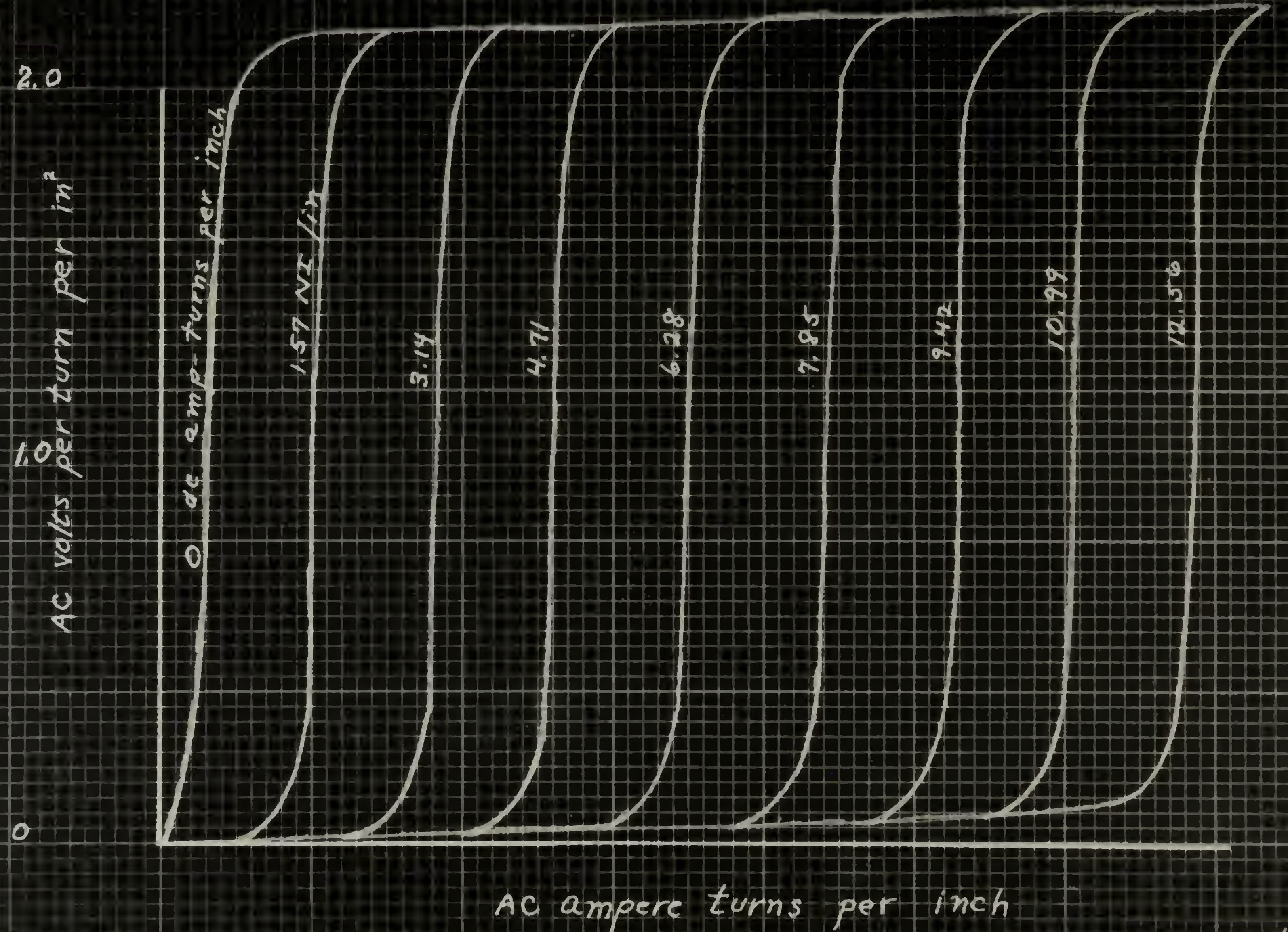
It is interesting to compare the 100 Kc curves with curves of the same iron at 400 cycles per second. The latter curves, figure ~~8~~ 7 on page 22 are typical of Hipernik at power frequencies. The resemblance between the two sets of curves is there but it is not obvious unless one realizes that the 100 kcs curves represent a region which would correspond to a very small part of the lower left hand corner of the 400 cps curves.

3. Summary of Measurements on Reactors

The data assembled thus far indicate that by application of small amounts of direct current, the reactance of the rf windings can be made to vary over about a ten to one range. The Q of the windings is too low to permit their insertion in a tank circuit without shunting them with a high Q air coil. The rf voltage applied to the windings may vary without detrimental effect. In a typical application the voltage across the reactors may be of the order of 25 volts. If this

Figure 7, Page 22

TYPICAL MAGNETISATION CURVES



Hipernik V Characteristic Curves at 400 ~ (AC windings in parallel)

voltage varied plus or minus 5 volts the reactance of the windings would not change provided the control and biasing current remains constant.

CHAPTER III

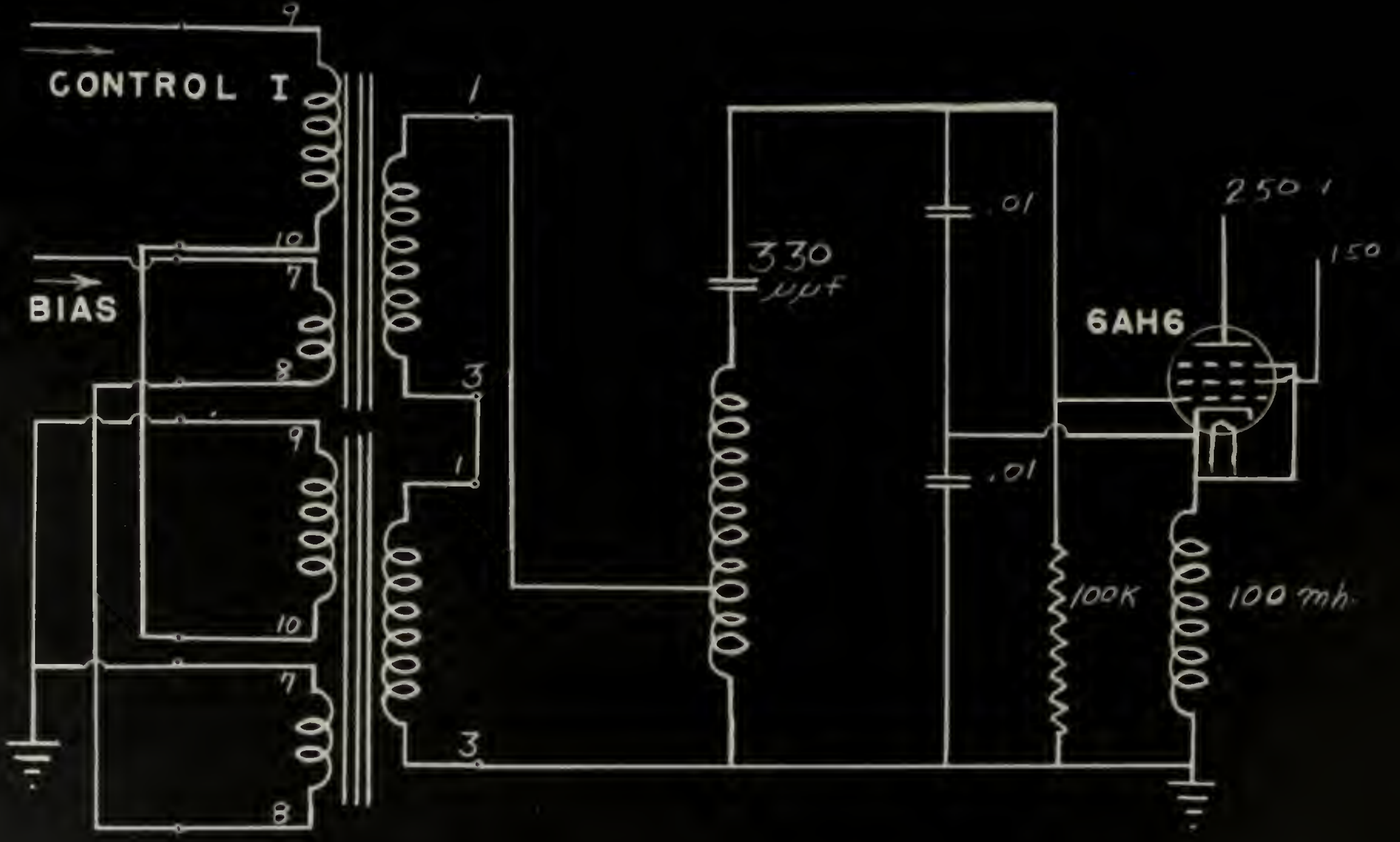
OSCILLATOR AND CONTROL CIRCUIT

1. Some Notes on the Clapp Oscillator

In order to give the control circuit composed of the Hipernik reactors a fair trial it seemed advisable to use an oscillator of inherently high stability. The oscillator which seemed to fill this requirement best was the Clapp oscillator. See Clapp (9). A schematic of the oscillator is shown on figure 8 page 25. A very similar circuit has been used in crystal oscillators. As an example of its previous use, see the General Radio 475C oscillator used in broadcast frequency monitors. The series LC circuit is the frequency dependent element of the oscillator. There is practically no tendency to spurious oscillations. Variation of plus or minus 15 per cent supply voltage does not vary the frequency of oscillation by more than a few parts per million. Tubes of the same type may be interchanged without changing the frequency. Greatest stability attains when plate and grid resistances of the tube are high and when the Q of the tank circuit inductance is high. Although no refinements such as temperature control were used in this investigation the drift was within 10 cycles per second per hour.

2. Control Circuit

The rf windings of the reactors are placed across about twenty percent of the inductance in the tank circuit. An attempt was made by a mathematical analysis to decide how much of the tank coil should be shunted but this method proved



OSCILLATOR & CONTROL CIRCUIT

Figure 8, Page 25

to be too lengthy. Trial and error turned out to be the better method. A high Q will result when the reactor is shunted across only a small part of the air core coil. The problem is to shunt as little of the air coil as possible and still get the reactive change necessary to shift the frequency of the oscillator.

Of course the air core coil could be wound with more turns in order to get more control with less shunting effect but that makes the L/C ratio higher. It might appear that the resonant circuit is loaded pretty heavily with the reactor circuit; however, there was never any indication that this loading had a deleterious effect on the stability of the circuit. A small resistor of the order of 200 ohms may be placed in the plate circuit of the 6AH6 for taking off the output; in the test runs the output was taken by capacitive coupling to one of the leads.

CHAPTER IV

OSCILLATOR MEASUREMENTS

1. Sensitivity Measurements

Restating the specific problem, it was desired to shift a 100 kc oscillator by 1,000 cps. This represents a frequency shift of one per cent. The parameter to be varied in the tuned circuit is the inductance. Since a high Q is necessary for the inductive element it seems reasonable to shunt a small portion of a high Q air core coil with the reactors. This is possible if the resulting circuit will give the necessary change of inductance. Assuming that a high Q will result:

$$\omega^2 = \frac{1}{LC}$$

if C is constant

$$\frac{d\omega}{\omega} = -\frac{1}{2C}\frac{dL}{L} = .01$$

$$\frac{dL}{L} = 0.02$$

Thus a two per cent change of inductance will result in the desired frequency shift. Since the inductance of the toroids alone can be varied over many times that amount it appears

that a workable circuit is possible. An air core coil was wound on a 1½ inch form. There were nine sections of 100 turns each. The Q of this coil was over 250 at 100 kc. The reactors, with rf windings in series were connected across two sections of the air core coil. This inductive element and a 330 micromicrofarad capacitor formed the frequency controlling element of a Clapp oscillator. See page 22 for circuit. A T-pad was used in the control winding in order to minimize any effect the impedance of the control circuit might have on the frequency. With various amounts of biasing current, the oscillator was shifted in frequency by varying the control current. General Radio 1105-A Primary Frequency standard equipment was used to observe frequency change. The curves of control ampere turns versus frequency shift are shown on figure 9, page 29. It is obvious that as the biasing ampere turns are increased the sensitivity of frequency to control current decreases. By examining the magnetization curves the reason for this decrease in sensitivity will become apparent. By using a fixed value of alternating voltage and computing the ratios of voltage to ampere turns at various values of bias ampere turns a permeability factor can be obtained. It will be noted that the change in permeability factor is not constant but decreases as the bias ampere turns are increased. Thus at higher bias the reactance changes more slowly.

2. Linearity Measurements

The linearity of the frequency shift with control current

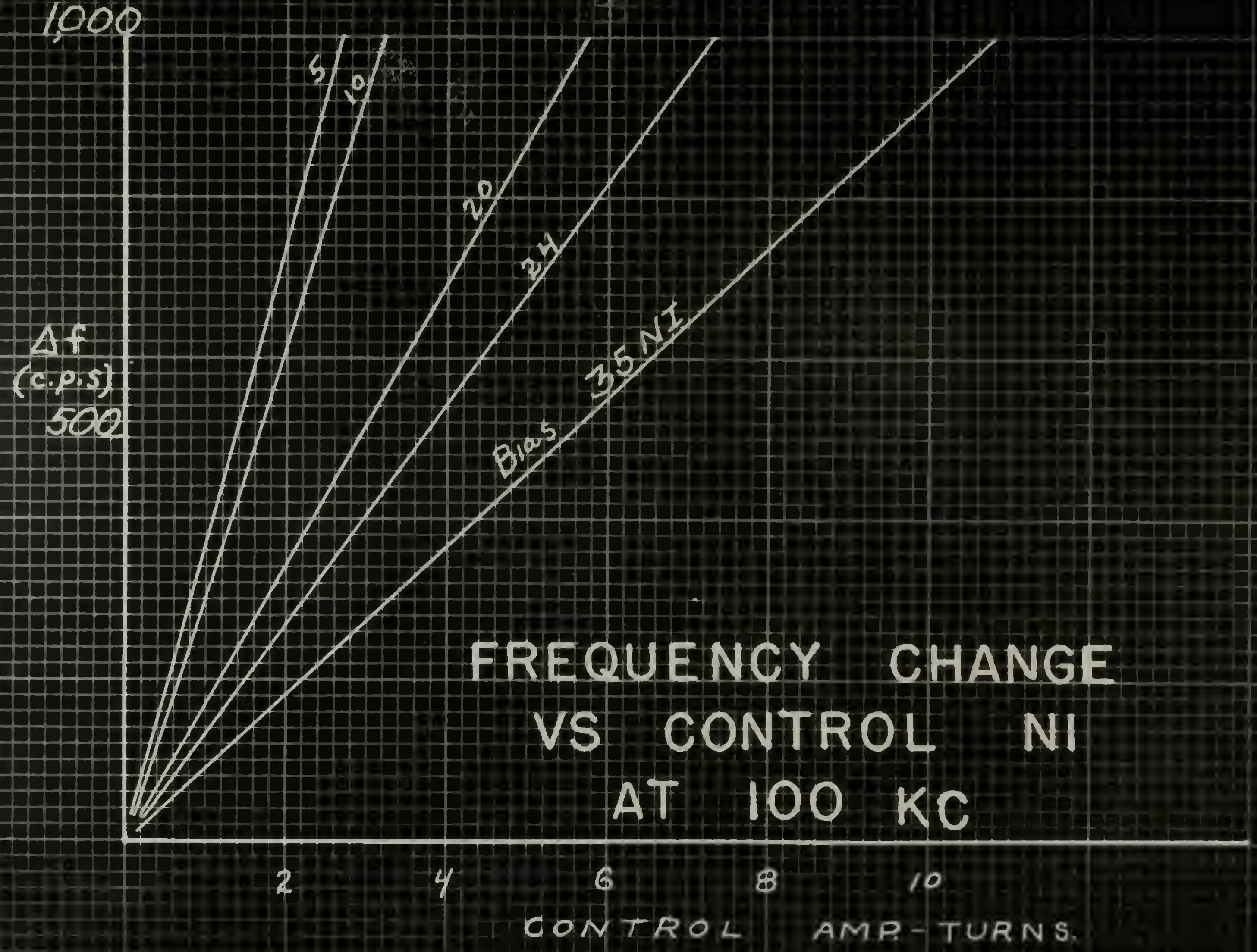
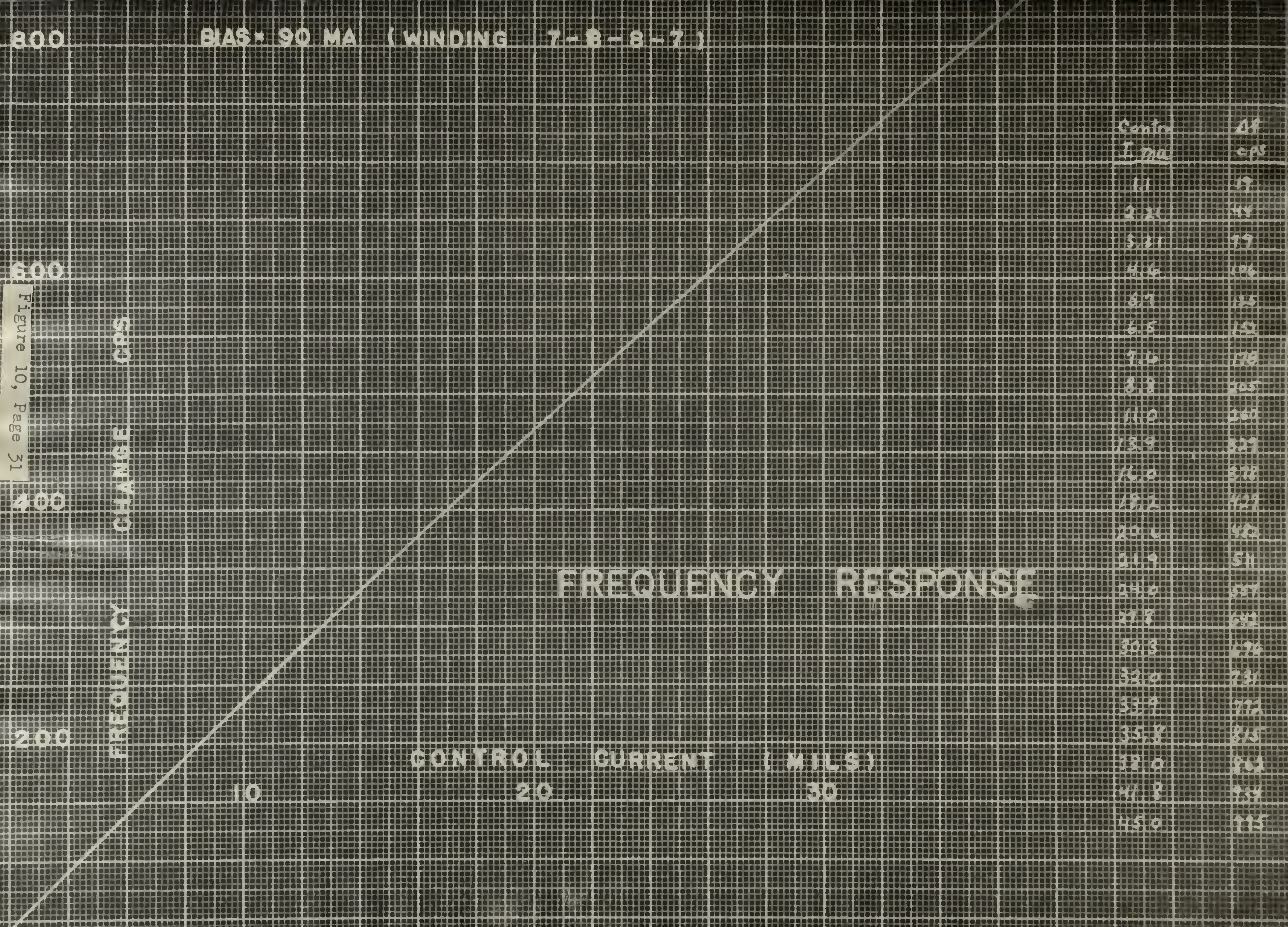


Figure 9 Page 29

is not quite within the limits specified on page 6. The curves on page 29 might mislead one into believing that the linearity is perfect. This particular plot was intended to show the relationship between various values of bias. The scale on figure 10, page 31, which is plotted on a more realistic scale shows a slight deviation from absolute linearity. Over most of the curve the slope of the line joining any two points is within ten per cent of the line joining the end points. At the extreme end, however there is a deviation which is closer to 15 per cent.

3. Hysteresis Effect

Soon after commencing the project it became apparent that the hysteresis effect would present one of the more difficult problems. It would indeed be anomalous for a piece of magnetic material to be without hysteresis; however previous experience of some engineers had not indicated that hysteresis would be important in this application. That is understandable in that this project was concerned with measurements of rather more than usual precision. It was found that if the control current were increased from a value A to B to C and then decreased from C to B to A, the frequency of the oscillator at the control current extremes was always the same but the frequency at current B depended upon the direction from which it approached. The discrepancy in frequency depended upon both the amount of biasing current and the amount of alternating voltage across the reactors. Increasing the dc flux or the ac flux reduced the amount of hysteresis. The greatest



Centr I ma	Δf cps
1.1	17
2.21	45
3.21	77
4.6	106
5.7	126
6.5	150
7.6	175
8.8	205
11.0	260
13.9	327
16.0	378
18.2	427
20.6	482
21.9	511
24.6	567
27.8	638
30.3	676
32.0	731
33.7	772
35.8	825
38.0	863
41.8	[illegible]
45.0	[illegible]

Figure 10, Page 31

effect noted was with 12 volts ac across the reactors and no biasing current. The frequency discrepancy was ten per cent of the frequency shift. The least effect noted was with 23 volts across the reactor and 60 ampere turns of bias. The frequency discrepancy in this case was only 0.16% of the total frequency shift. In the former case the discrepancy is intolerable in a stable oscillator; in the latter case the discrepancy is less than two cycles. These readings were made on an Esterline-Angus recorder which was connected to the interpolation oscillator (GR-1107A). They were repeated many times. There seems to be no ready explanation of why the hysteresis is reduced by increasing the ac flux. Only a very qualitative sort of explanation has emerged to explain why the hysteresis is reduced with increase in dc flux. Referring to the magnetisation curves of page 20 , by using some value of ac as a locus, it can be seen that the slope of the bias lines decrease as the bias is increased. The magnetisation curves can be thought of as a plot of the end points of a series of hysteresis loops. At the extremes of dc hysteresis loop the hysteresis loss is practically zero. The maximum amount of hysteresis is at the zero flux positions. See Terman (46). The greatest hysteresis is associated with the steep part of the BH curve. Similarly, on the magnetisation curves, the hystersis is greatest where the slope of the curve is steepest.

The hysteresis effect can be reduced to a negligible amount by proper choice of operating point; however the operating point for low hysteresis is also associated with low

sensitivity. This of itself may not be a prohibitive condition but other factors such as the number of ampere turns enter this problem. If the number of control turns is increased the response time of the reactor increases.

4. Response Time

The inductance of the windings of a reactor lead one to the inescapable conclusion that there is an inherent delay in any circuit employing reactors. The time delay is due almost entirely to the control circuit. In the case of parallel connected reactors there is a time delay associated with the rf windings. This has been measured in magnetic amplifiers and is of the order of twice the delay measured in the series connected circuit.

An immediate solution that comes to mind is to reduce the ratio of L to R in the control winding by increasing the resistance. This is an answer but like most other solutions to problems caused by natural laws there is a price to pay. Such a solution to the problem would result in further decrease in the sensitivity of the reactors. If there is no limit to the current available the problem becomes insignificent.

It was determined by cathode ray oscilloscope photographs of the oscillator output that above 200 words per minute keying speeds there is noticeable deterioration of the square wave. Present day design objectives for on off frequency shift keying aim for speeds about 600 words per minute.

Very little time was spent on this phase of the problem

because a great deal of work has already been done on this subject and very little new knowledge could be added. See Westinghouse (47, Harder (19), Beaumariage (3).

CHAPTER V

CONCLUSIONS

Hipernik reactors can be employed in frequency shift oscillators at frequencies near 100 kc. Whether or not they can be employed in a 100 kc oscillator in which 2 cycle stability and reset accuracy is required remains to be answered. It does seem promising because of at least two factors. The rf winding of the cores used had a Q of 4 with no dc flux applied. By using one mil foil, which is commercially available, the Q could theoretically be increased to about 16. Furthermore, in winding the reactors very little attention was given to keeping the capacity of the windings low. It is believed that by taking care to do so in the next attempt will result in a lower loss component.

Generally, the results proved to be quite satisfactory. For on-off keying at speeds below 200 words per minute the oscillator can be shifted by the application of 15 milliamperes to the control winding. The power requirements for such a circuit are negligible. In order to shift the oscillator by the output of a facsimile machine hysteresis effect must be considered. To reduce the hysteresis effect, bias is necessary. Although the amount of current required may be of the order of 200 milliamperes, depending on the number of turns in the bias winding, power is again not a problem. Single receiving type tubes could be used. The regulation of the biasing current must be high. It should be remembered that any variation of bias current will have the same effect as a change in signal

current; furthermore, if the bias winding has more turns than the control winding, which is highly probable, the variation of bias current will override the signal current.

The long life feature of reactors should be an attractive feature to the designer who is considering the maintenance problem. It is hoped that further study will result in this application finding its way into operational equipment.

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APPENDIX

REACTOR APPLICATIONS

Lighting reactor

DC current transformer

Automatic battery charger

Constant voltage rectifier

Voltage regulator

Current regulator

Frequency regulator

Photocell amplifier

Thermocouple amplifier

Relays (where zero current is not required)

Variable d-c motor drive

Firing controls for Ignitrons

Induction motor speed control

Synchronous motor starter

Servo-amplifier

Controls for various types of valves

Audio amplifier

Computer amplifier for fire control

Stabilizers for gun mounts and range finder

Antiaircraft detector

Automatic pilot controls

Automatic direction indicators


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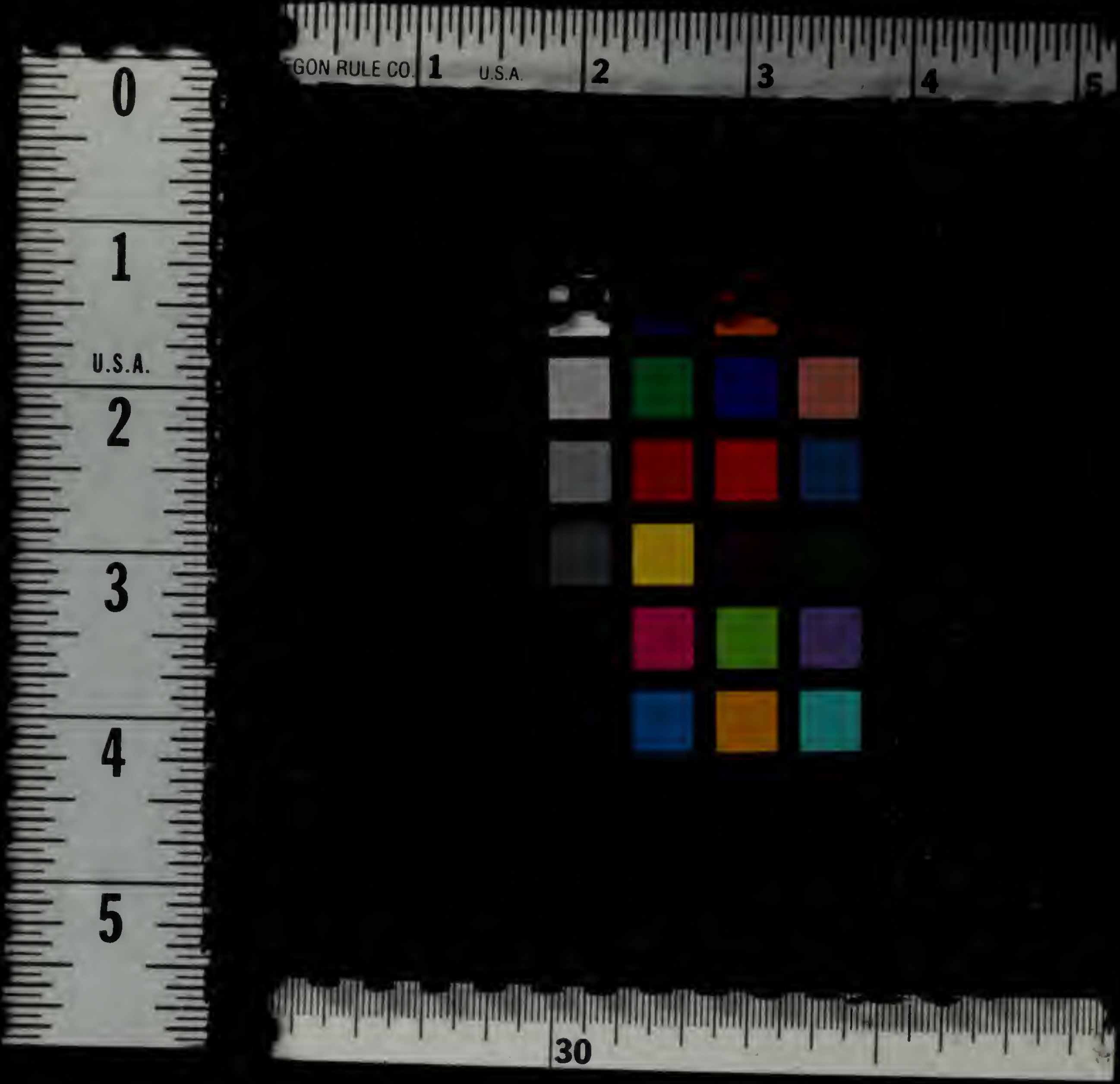
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