A METHOD OF GRADING MOLYBDENUM PERMALLOY TOROIDAL CORES TO PREDETERMINE REQUIRED TURNS FOR A GIVEN INDUCTANCE

by

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I INTRODUCTION

Molybdenum permalloy powder cores are manufactured to meet specific dimensional tolerances and to fall within required permeability limits. However, for any particular core size the inductance of individual coils for any given number of turns will vary considerably. For example, for cores designated A-930157-2, manufactured by the Arnold Engineering Company to the same specifications used by the Western Electric Company, with a 1000-turn winding, the inductance may range from 135 to 179 millihenries. This indicates a variation of ±14% from a nominal value of 157 millihenries.

It is therefore highly desirable that large-scale users of these cores grade them into groups by some simple inductance test. This permits cores to be wound with a predetermined number of turns, thereby essentially eliminating the labor of adjusting the turns of the winding to meet required inductance values.

II THE REVIEW OF LITERATURE

The bulletin prepared by the Arnold Engineering Company (4) contains the specifications for 125 permeability cores, and briefly states methods employed to grade cores prior to winding. Temperature stability and moisture-absorption effects are discussed in this bulletin and in an article by Mr. C. D. Owens (7). In 1924, Mr. G. A. Kelsall (6) described a test jig suitable for grading cores, where the core under test is coupled by use of a single-turn secondary to a transformer having a multi-turn primary. The inductance of the core is reflected into the primary of the transformer and measured. The brochure prepared by the Boesch Manufacturing Company (5) presents the description of their permeameter, which uses a Kelsall-type test jig. The use of this permeameter requires that a standard coil of correct inductance with a nominal reading core be made for each different winding detail. The cores are then graded in terms of the number of turns used on the standard core and are limited for use only on one winding detail.

Equipment to be used in the test circuit to grade cores and to read inductance values of finished coils is discussed by Mr. M. B. Stout (1). A paper on the Owen bridge, a modification of which will be used to measure the inductance readings, was presented in 1915 by Mr. D. Owen (2). In 1927 Mr. J. G. Ferguson (3) presented a paper on the shielded Owen bridge.

III THE INVESTIGATION

Object of the Investigation

This work has the following purposes:

(1) To design and construct a multi-turn split jig suitable for rapid testing of cores to permit economical grading;

(2) To construct a modified Owen alternating-current bridge with component capacitor and resistor values such that the inductance values of the unwound cores and the finished coils may be read directly from one decade resistance box in microhenries and millihenries, respectively.

(3) To prepare a family of curves each representing a group of graded cores showing the number of turns required to yield a given inductance.

Method of Procedure

A multi-turn split jig and a modified Owen inductance bridge, constructed with standard laboratory components, was used to economically grade the cores. The multi-turn split jig rapidly performs the same function as hand winding 12 turns on each core; also, the jig provides a uniform winding for each core, whereas individual windings introduce a variable. Thus the only variable is each individual core ring. A sketch of the jig and the test circuit used to grade cores are shown in figures 1 and 2. The bridge is balanced with the test jig in the circuit with no core in place. Then a core is put in the jig and a reading obtained. A frequency of 40 KC is used in order for a twelve-turn winding to present adequate inductive reactance to unbalance the bridge.

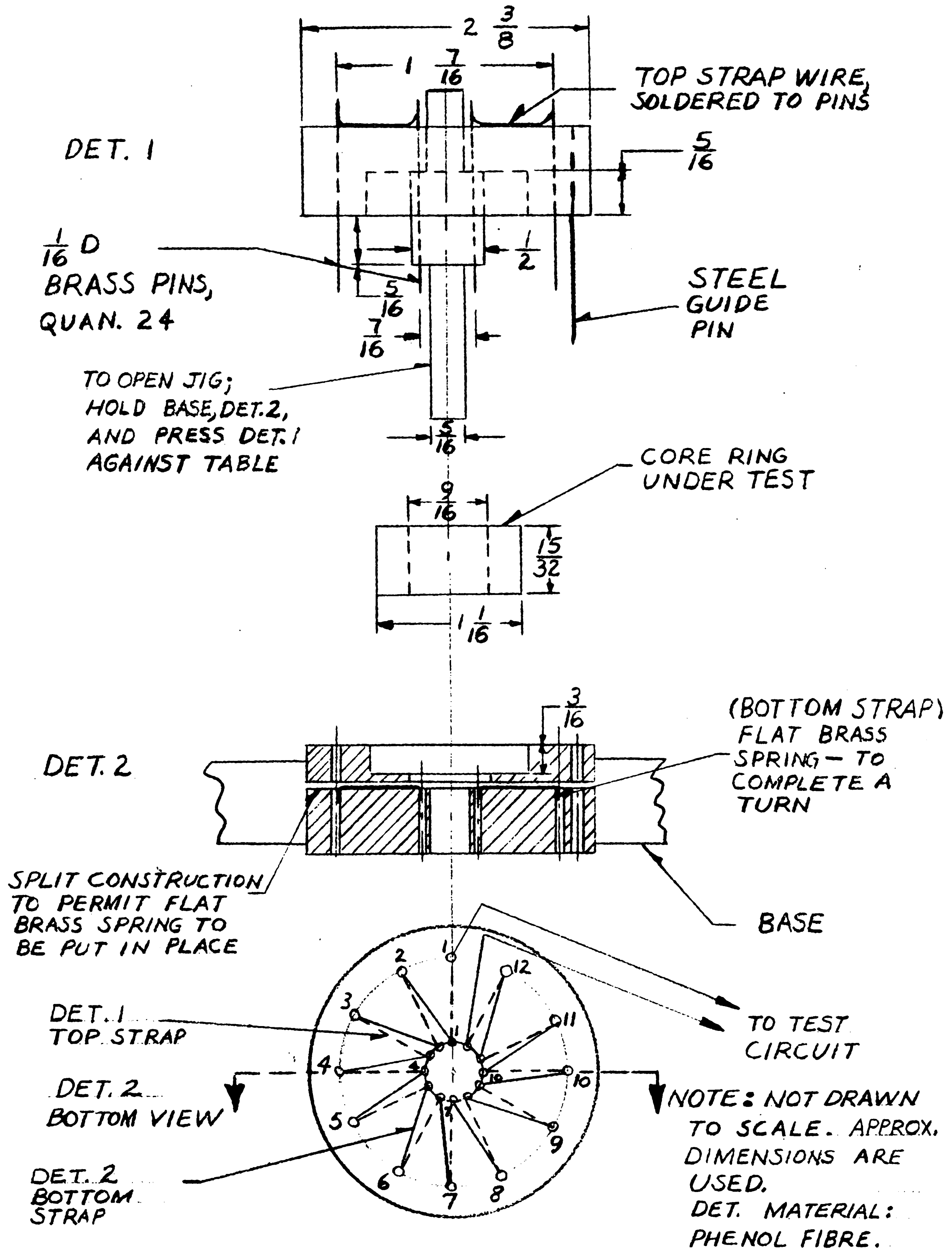


FIGURE 1

SIMPLIFIED SKETCH OF THE 12-TURN SPLIT JIG

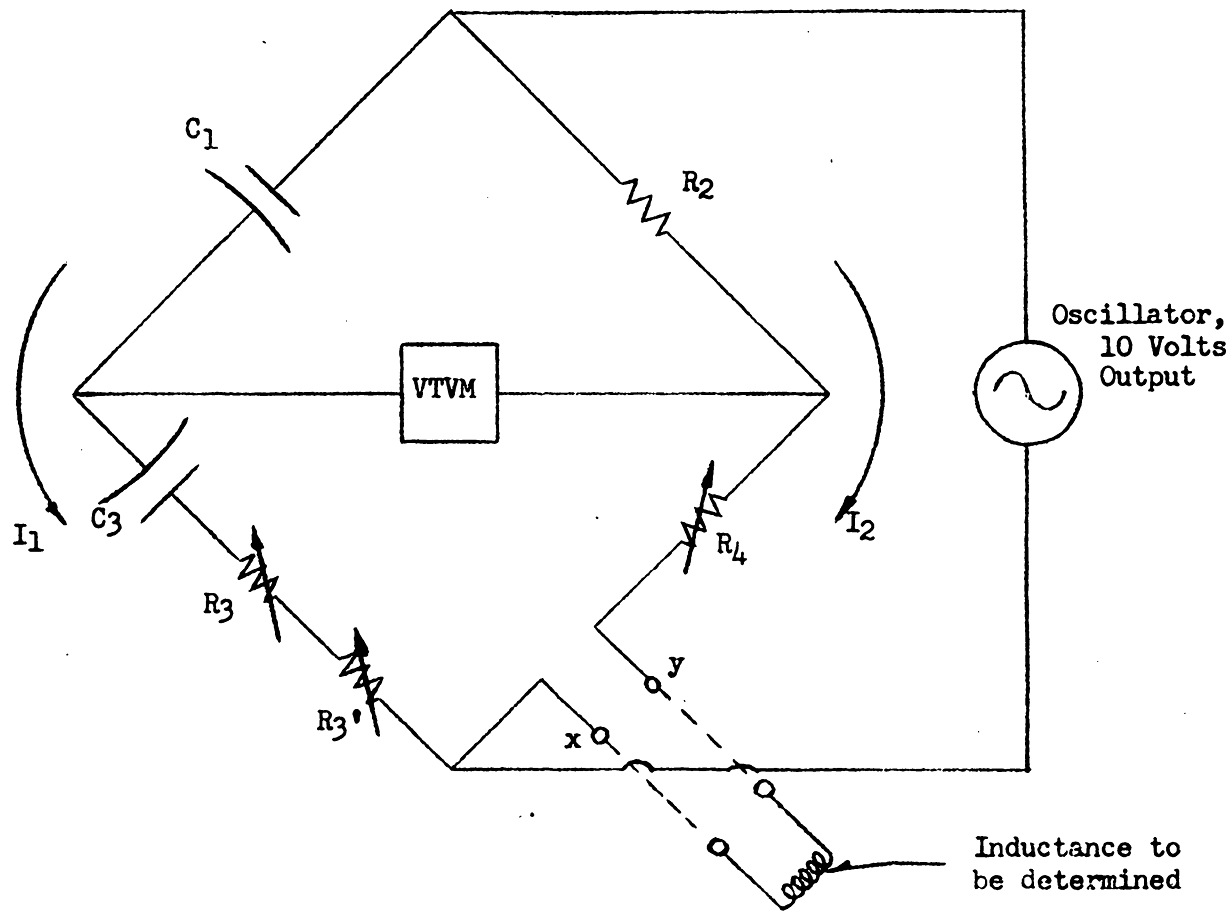


Figure 2

CIRCUIT FOR MODIFIED OWEN
ALTERNATING-CURRENT BRIDGE

After grading, the cores were wound on a Boesch toroidal winding machine with an electronic counter which accurately counted the turns of each section of the winding. The winding and splicing was done by the Western Electric Company's Lexington Road Plant in Winston-Salem, North Carolina.

After the windings were completed, the Owen alternating-current bridge was used to determine the inductance of each section of the winding and various additive combinations of winding sections of the finished coils. By winding four sections, each with a different number of turns, it was possible to obtain a large number of inductance readings for each winding. The readings of the Owen bridge have the advantage of being independent of the frequency of the source and depend only on the accuracy of the bridge components.

A schematic diagram and a photograph of a coil are shown in figures 3 and 4. The procedure for balancing a similar bridge and measuring inductance is explained in Stout (1). Mr. Stout also gives an outline derivation of the equation for inductance. The detailed derivation of the equation for effective resistance and inductance, and the procedure for balancing the bridge and measuring inductance is given as follows:

SECTION	TURNS	COLOR OF LEAD WIRE	
		INNER END	OUTER END
A	300	RED	RED-WHITE
B	350	BLUE	BLUE-WHITE
C	400	BROWN	BROWN-WHITE
D	450	GREEN	GREEN-WHITE

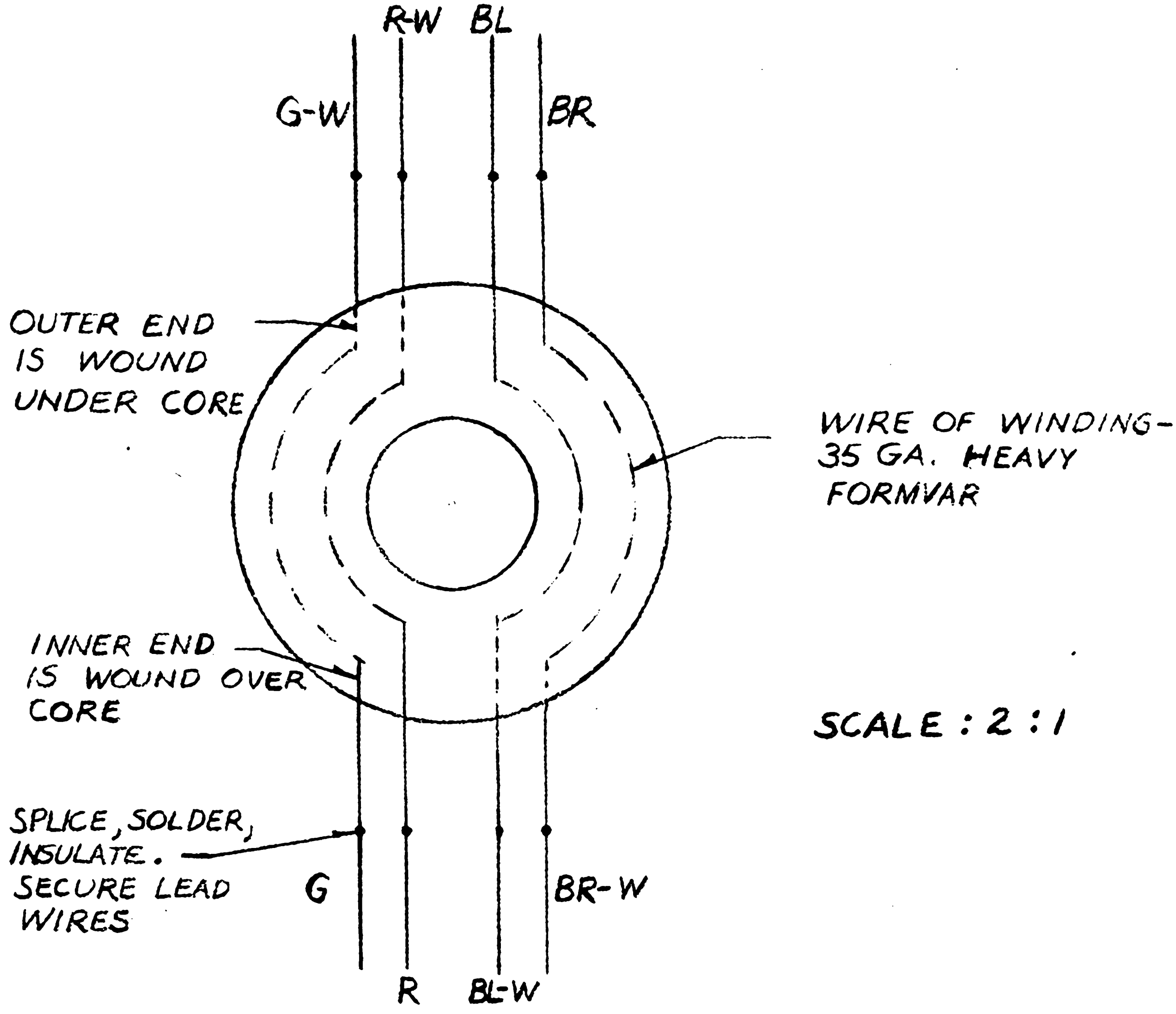
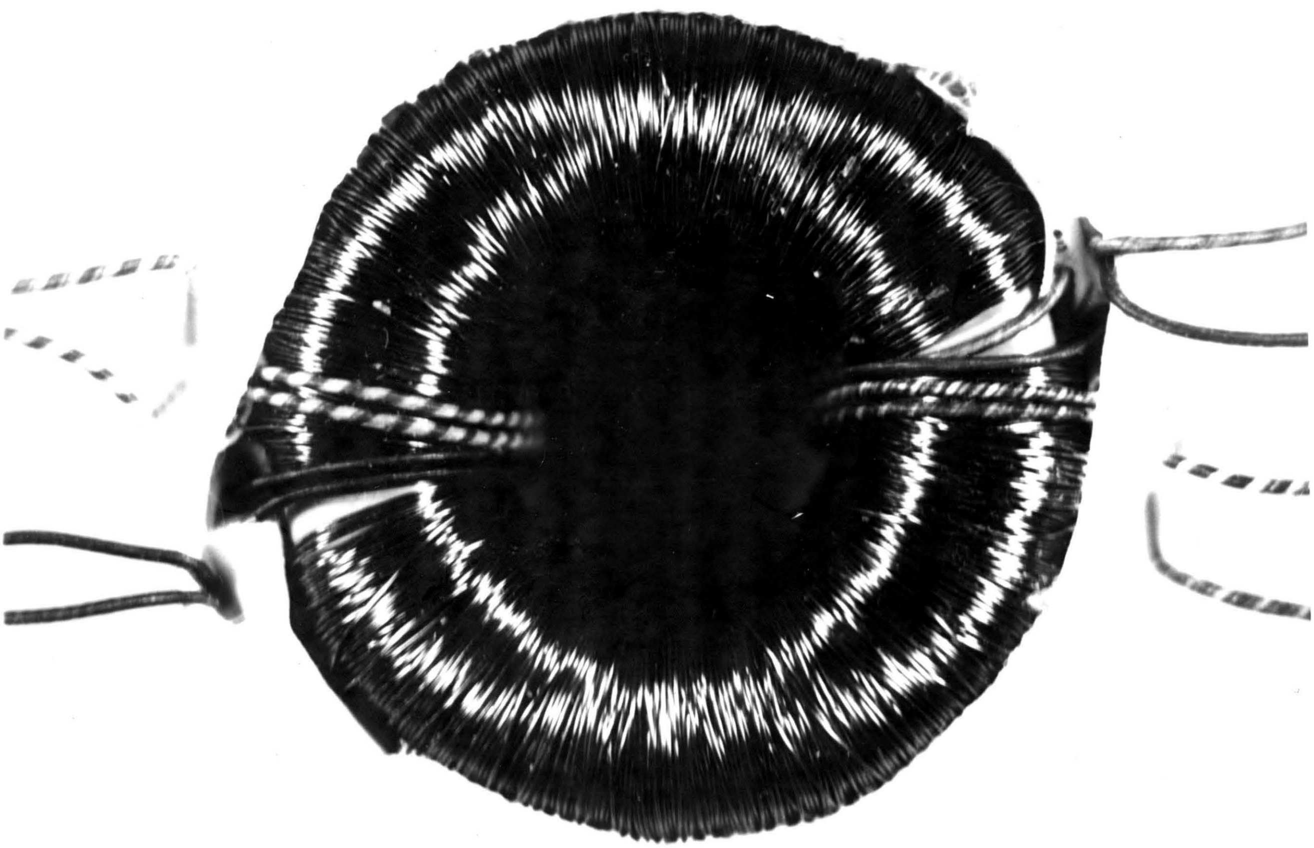


FIGURE 3

SCHEMATIC DIAGRAM OF A COIL

Figure 4

ENLARGED PHOTOGRAPH OF A COIL



I. TO BALANCE BRIDGE:

Set the frequency to 40 KC. Place closed jig, L_x, across terminals x, y; set $R_3' = 0$; and balance by adjustment of R_4 and R_3.

At a balanced condition,

(1) $$-j X_{C_1} I_1 = R_2 I_2$$

(2) $$I_1(R_3 - jX_{C_3}) = (R_4 + R_{L_x} + jX_{L_x})I_2$$

Divide (1) by (2)

(3) $$X_{C_1} X_{L_x} - jX_{C_1}(R_4 + R_{L_x}) = R_2 R_3 - jX_{C_3} R_2$$

Separation of real and j terms yields,

$$\frac{R_4 + R_{L_x}}{C_1} = \frac{R_2}{C_3}$$

(4) $$R_4 = \frac{R_2 C_1}{C_3} - R_{L_x}$$

$$\frac{L_x}{C_1} = R_2 R_3$$

(5) $$L_x = C_1 R_2 R_3$$

II. TO READ INDUCTANCE OF CORE, L_x':

Add core to be graded to jig; balance by adjustment of R_4 and R_3'. Designate the balanced reading R_4' and the increased inductance L_x'. By similar analysis,

(6) $$R_{L_x'} = R_4 - R_4' \quad \text{and}$$

(7) $$L_x' = C_1 R_2 R_3' \quad \text{where}$$

$C_1 = .103 \times 10^{-6}$ farad and $R_2 = 9.7$ ohms.

Since $C_1 R_2 = 1 \times 10^{-6}$, R_3' reads directly in microhenries; therefore, $L_x' = R_3'$ microhenries. For the set of readings taken, $C_3 = C_1$.

III. TO READ INDUCTANCE OF FINISHED COIL, L_x:

Set the frequency to 1 KC. Also let L_x equal the inductance of a wound coil. Short terminals x, y; set R_3 and $R_3' = 0$; and balance by adjustment of R_4. By similar analysis,

(8) $R_4 = \frac{R_2 C_1}{C_3}$ and with the coil present,

(9) $R_{L_x} = R_4 - R_4'$ where R_4' is the balanced reading and

$L_x = C_1 R_2 R_3$ where

$C_3 = C_1 = 1.005 \times 10^{-6}$ farad and $R_2 = 995$ ohms.

Since $C_1 R_2 = 10^{-3}$, R_3 reads directly in millihenries; therefore, $L_x = R_3$ millihenries.

Finally, a family of curves was prepared, each representing a group of graded cores showing the relationship between turns and inductance.

Equipment

A photograph of the 12-turn split jig and a toroidal core is shown in figure 5. A photograph of the modified Owen bridge with the jig in place is shown in figure 6. The equipment used in the bridge is as follows:

General Radio Company decade resistor boxes,

R_2 - Serial Number 2766.

R_3 - Serial Number 11270.

R_3' - Serial Number 11289.

R_4 - Serial Number 10882.

Leeds and Northrup Company decade capacitor boxes,

C_1 - Serial Number 1189173.

C_3 - Serial Number 1189171.

Hewlett Packard audio oscillator, Model 200AB, Serial Number 3416.

Hewlett Packard vacuum tube voltmeter, Model 400D, Serial Number 1912.

Results

The inductance readings of the cores prior to winding and the readings of various additive combinations of turns of the finished coils are shown in table 1. The curves, each for a group of cores, showing the relationship between turns and inductance for the finished coils are shown in figures 7, 8, and 9.

Table 1

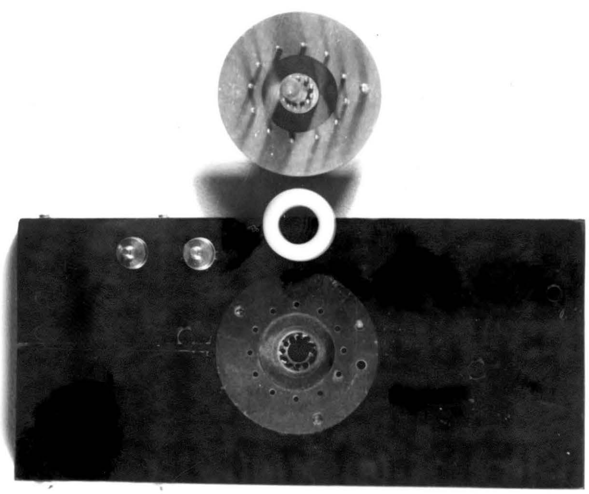
Inductance Readings of the Cores Prior to Winding and the Readings of Various Additive Combinations of Turns of the Finished Coils.

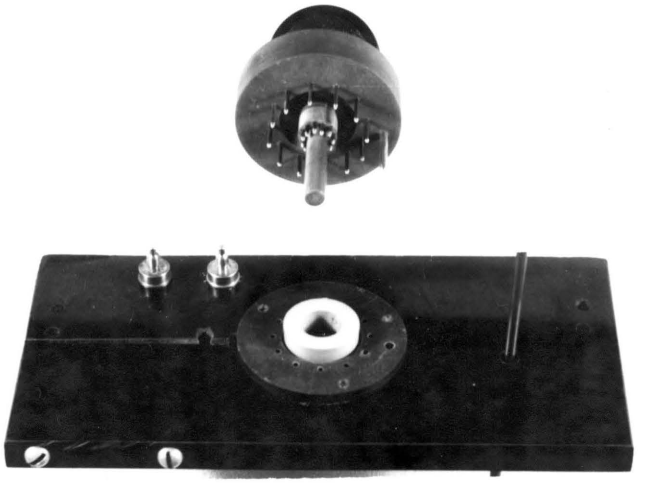
CORE DESIGNATION	L_x' IN MICROHENRIES AT 40 KC	L_x IN MILLIHENRIES AT 1 KC — TURNS					
		300 750	350 1050	400 1100	450 1150	650 1200	700 1500
A-1	18.92	12.9 82.0	17.7 152.1	23.6 165.9	29.7 181.7	57.0 197.6	66.9 307.0
B-1	19.97	13.7 88.0	18.6 160.9	24.5 177.9	32.0 194.4	60.4 210.5	70.6 327.8
B-2	19.95	13.5 85.4	18.7 160.0	24.7 174.1	30.9 190.4	60.0 207.6	70.2 322.6
C-1	21.07	14.3 90.9	19.6 169.6	25.8 185.9	32.8 202.4	63.9 220.5	74.2 343.5
C-2	21.07	14.4 91.5	19.8 170.0	25.9 186.2	33.1 203.1	64.2 220.3	74.6 343.7
D-1	22.02	15.0 94.8	20.5 177.3	27.2 193.8	34.3 211.8	66.7 230.6	77.9 358.8
D-2	22.02	15.0 94.6	20.7 177.2	27.0 193.2	34.0 210.9	67.0 229.2	77.8 357.5
E-1	22.98	15.6 98.5	21.4 184.5	28.0 201.9	35.5 219.9	69.8 239.3	80.9 373.1
E-2	22.98	15.7 99.2	21.4 184.2	28.0 201.8	35.8 220.6	69.6 238.9	81.1 373.0
F-1	23.93	16.3 102.0	22.2 191.9	29.2 209.3	36.7 228.5	72.5 248.3	84.4 387.5
F-2	23.98	16.4 103.4	22.3 193.7	29.6 211.3	37.2 231.4	73.0 250.9	85.4 391.5

Figure 5

PHOTOGRAPH OF THE 12-TURN

SPLIT JIG AND A TOROIDAL CORE





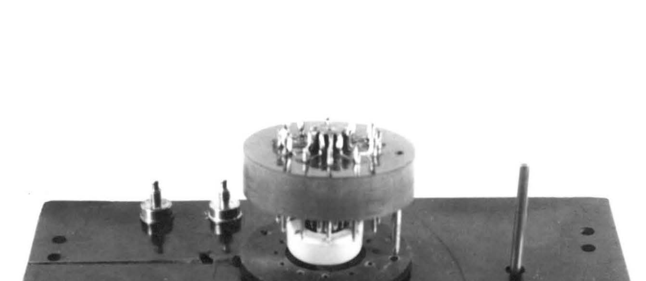
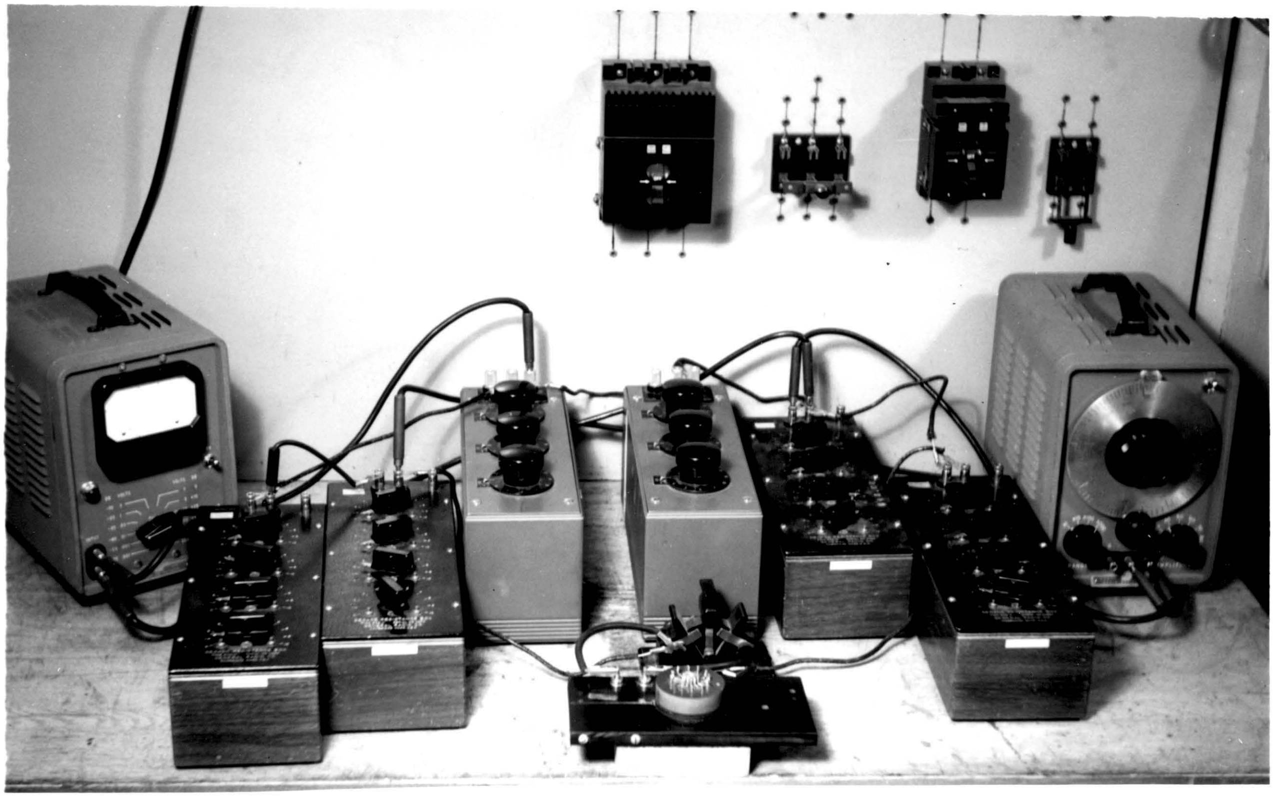


Figure 6

PHOTOGRAPH OF THE MODIFIED OWEN

BRIDGE WITH THE JIG IN PLACE



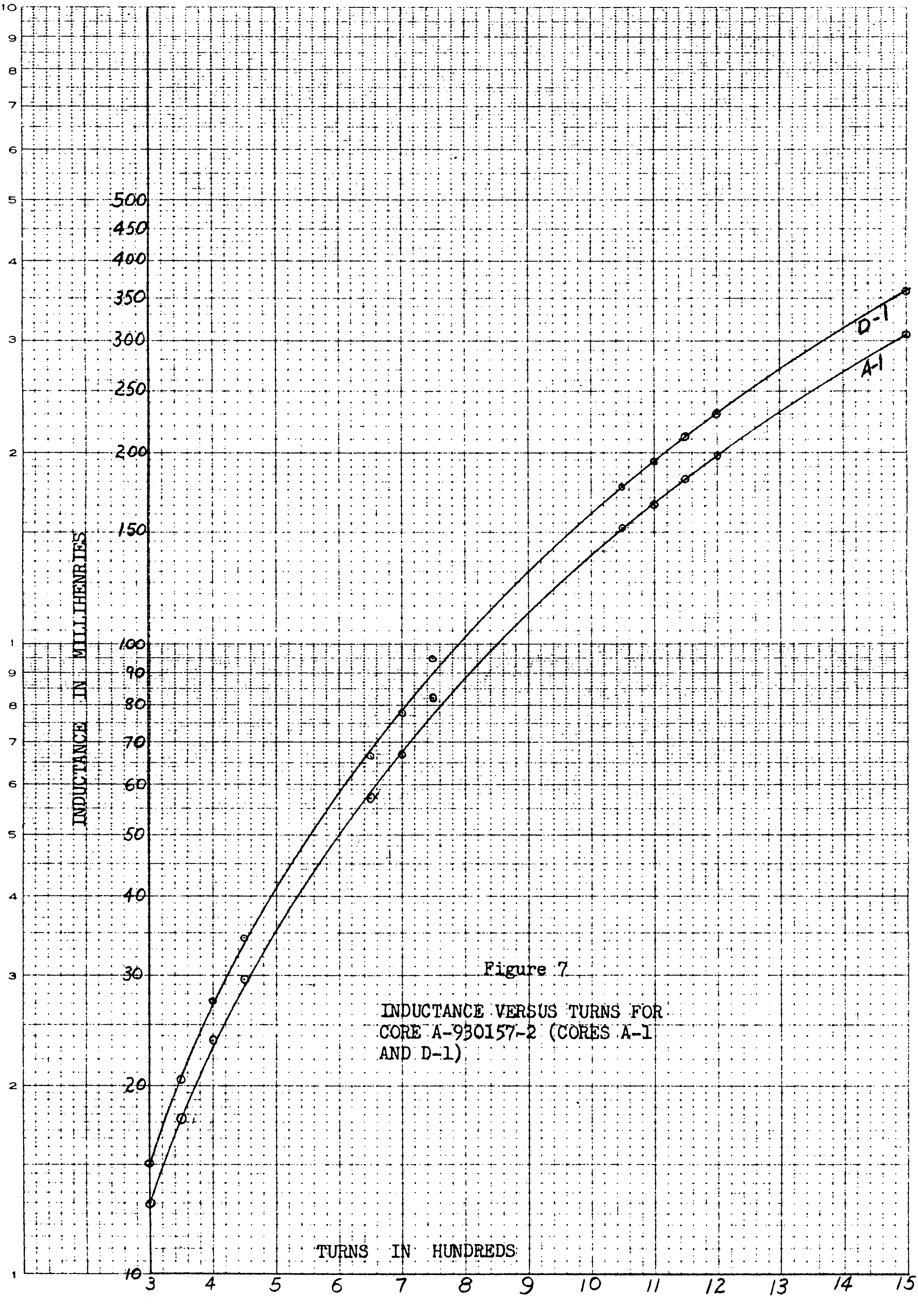


Figure 7

INDUCTANCE VERSUS TURNS FOR CORE A-930157-2 (CORES A-1 AND D-1)

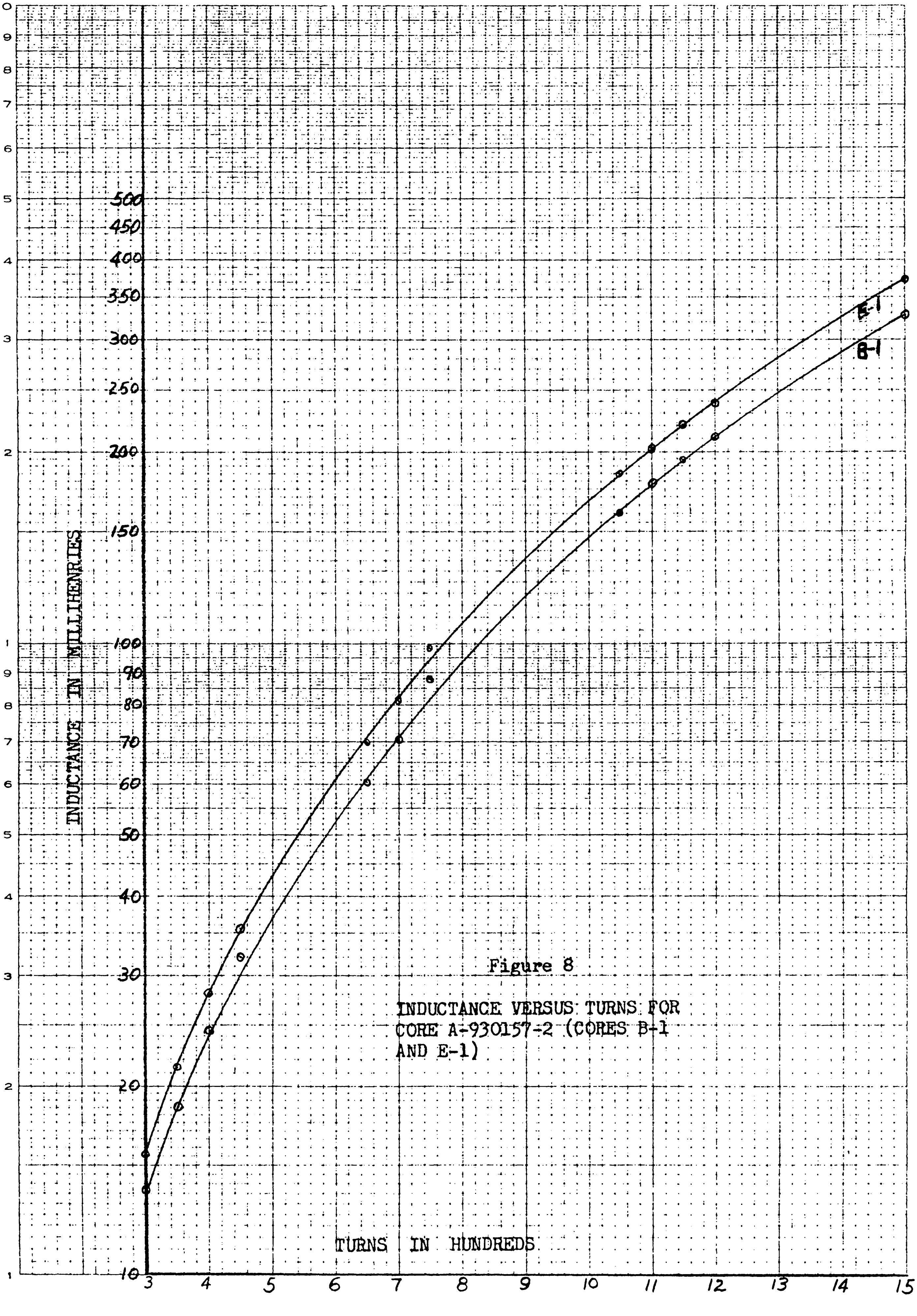


Figure 8

INDUCTANCE VERSUS TURNS FOR CORE A-930157-2 (CORES B-1 AND E-1)

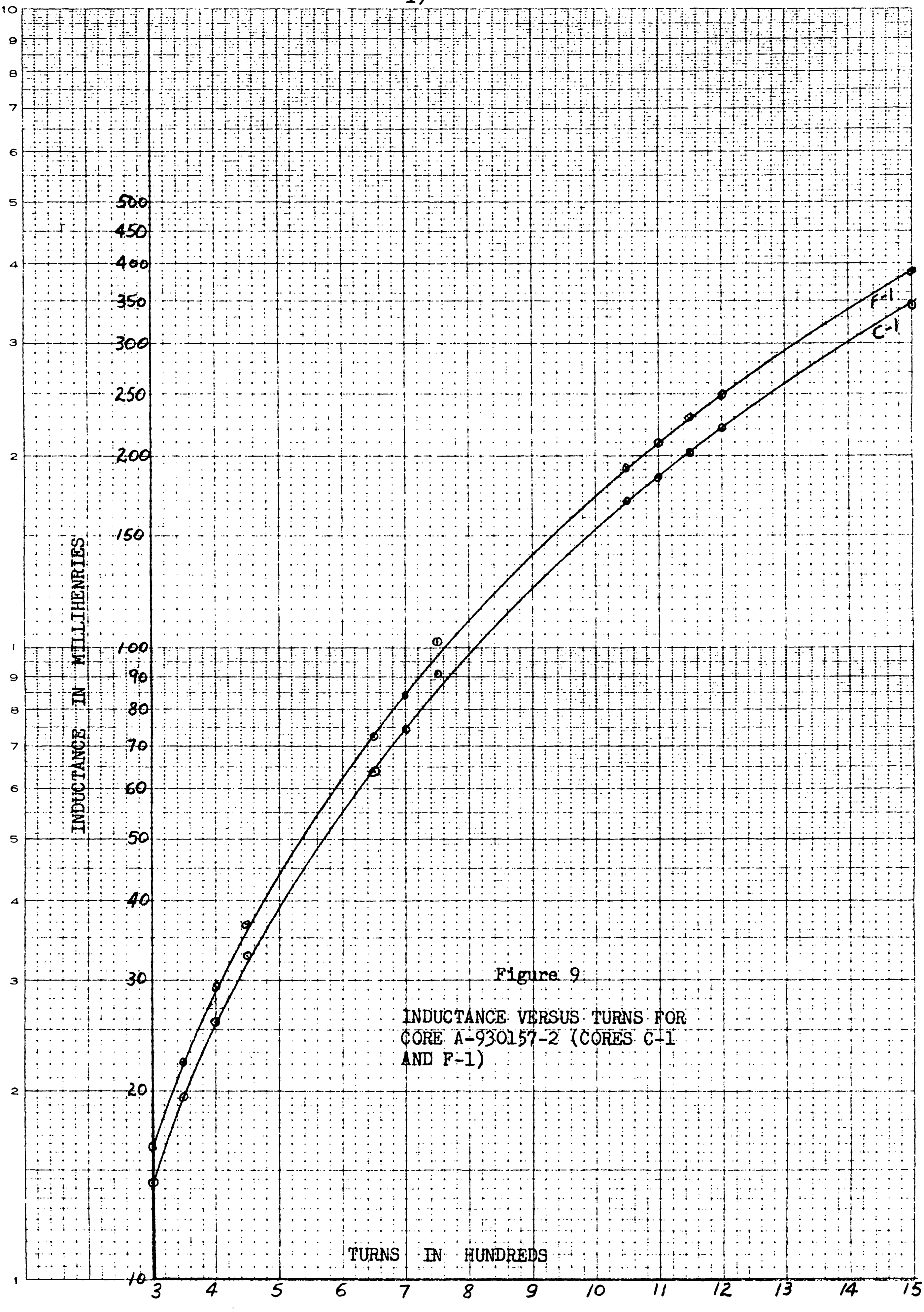


Figure 9

INDUCTANCE VERSUS TURNS FOR CORE A-930157-2 (CORES C-1 AND F-1)

IV DISCUSSION OF RESULTS

In view of the fact that the second place beyond the decimal point was estimated when the cores were graded and the fact that slight winding variations and small errors in the turn-count occur, the results are gratifying. Detailed examination of the results shows that for 1500 turns on each winding, the ratio of the inductance values for any given pair of coils is generally within 1% of the ratio of the inductance values of the respective graded cores.

A large number of cores were graded, and eleven of these were chosen to become finished coils. Whenever possible two cores which read almost the same were selected to represent a group of cores. Group A has only one core, groups B through F have two cores each. Excellent correlation was obtained within and between each group.

For the presentation of the turns required to yield a given inductance for a core within a group, the data of the first core from each group was chosen to illustrate this relationship. Only a few of the possible number of curves were obtained for the core size used. In actual practice, curves would be furnished to the shop for each group of cores sorted. Several curves can be shown together, provided each group is appreciably different in value to provide adequate spacing between the curves.

If the requirements were such that a particular winding detail should be within ±1% of a nominal inductance value, it would be practical to grade the A-930157-2 cores in 0.2 microhenry steps, since the average reading for this core with a 12-turn jig slightly exceeds 20 microhenries.

Theoretically, the windings would be wound within ±.5% of the nominal value, provided the curve was constructed with a core falling exactly in the center of a graded group.

It should be noted that the inductance of the finished coil of 1500 turns slightly exceeds the product of the inductance increase due to the core used and the ratio of the turns of the coil and jig squared. This is to be expected since the diameter of the turns on the finished coil is considerably smaller than the diameter of the turns of the jig.

V CONCLUSIONS

From the results obtained it can be concluded that cores can be economically graded into groups by a simple inductance test with relatively inexpensive test equipment readily available in coil shops. The grading permits a winding machine operator to wind coils with the same number of turns for perhaps an entire work-day, with the coils requiring little or no turn adjustment to meet specified inductance limits.

VI RECOMMENDATIONS

To increase the rate of core grading, it would be highly desirable to replace the R_3 and R_3' decade resistor boxes with slide wire dial type resistors whereby the resistance could be continuously changed by manipulating one dial only. Also the top portion of the grading jig should be mounted in a suitable arrangement so that the jig could be rapidly opened and closed by the simple movement of a lever.

Prior to splicing the lead wires to the windings, the process testing can most economically be made on an impedance comparator, where the winding to be adjusted is rapidly compared against a standard coil made from one of the production winding details.

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ABSTRACT

Molybdenum-permalloy powder cores are manufactured to fall within required permeability limits. However, these limits are sufficiently broad to cause sizeable labor loss in adjusting the number of turns for required inductance values; for example, an Arnold Engineering Company A-930157-2 core with a 1000-turn winding may range from 135 to 179 millihenries. It is therefore highly desirable that large-scale users of these cores grade them into groups by some simple inductance test. This permits cores to be wound with a predetermined number of turns, thereby essentially eliminating the labor of adjusting the number of turns of the winding to meet required inductance values.

The following work has been accomplished:

(1) The design and construction of a multi-turn split jig suitable for rapid testing of cores to permit economical grading.

(2) The construction of a modified Owen alternating-current bridge with component capacitor and resistor values such that the inductance of the unwound cores and the finished coils may be read directly from one decade resistance box in microhenries and millihenries, respectively.

(3) The preparation of a family of curves each representing a group of graded cores showing the number of turns required to yield a given inductance.

Sketches and photographs of a core, finished coil, multi-turn split jig, and the test circuit are included.