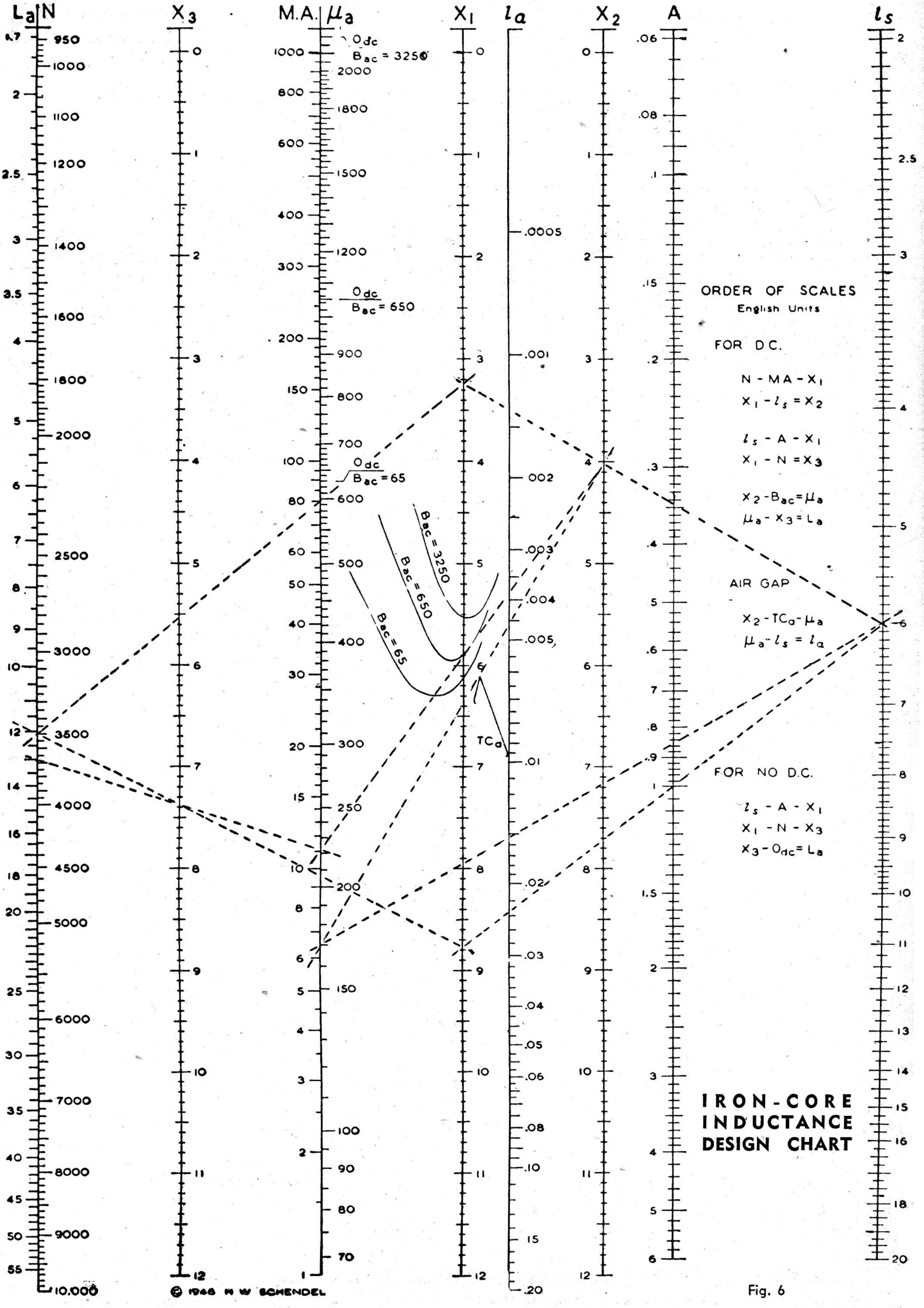

ORDER OF SCALES
English Units

FOR D.C.

$N - MA - X_1$
$X_1 - l_s = X_2$

$l_s - A - X_1$
$X_1 - N = X_3$

$X_2 - B_{ac} = \mu_a$
$\mu_a - X_3 = L_a$

AIR GAP

$X_2 - TC_a - \mu_a$
$\mu_a - l_s = l_a$

FOR NO D.C.

$l_s - A - X_1$
$X_1 - N - X_3$
$X_3 - O_{dc} = L_a$

IRON-CORE INDUCTANCE DESIGN CHART

Fig. 6

COILS, CORES AND MAGNETS

By H. W. SCHENDEL

Part II—Reactor and Transformer Measurement and Design

FILTER chokes or reactors, audio frequency chokes, and audio transformers come under the classification of iron-core inductances. The unit of inductance is the *henry*. A coil has an inductance of one henry if a current changing at the rate of one ampere in one second induces one volt in it.

Basically inductances are the same as electromagnets and use cores like the relays described in the first part of this article. The essential difference is that inductance is the main consideration. This in turn depends on the permeability of the steel or alloy.

Considerable care is required in rewinding good grade audio devices but it is a comparatively simple matter to rewind filter chokes and obtain approximate original characteristics. If a unit is rewound with original size wire, with about the same number of turns, and close attention given the size of air gap, if any, no trouble should be encountered. *When an air gap has been used its size is extremely important.* In some cases a change of .001 inch in air gap total length will cause a 50 percent change in final inductance. Generally speaking it is better to err slightly oversize rather than undersize.

Much valuable information on rewinding, including a copper wire table, appeared in articles in the Aug.-Sept., October, and December 1942, and the September 1943 issues of RADIO-CRAFT.

To rewind an iron-core inductance for other than original conditions or to design one for some specific purpose involves several factors.

Windings of iron-core coils carrying only a.c. have an inductance which varies in relation to the induced flux in a manner similar to the variation of the d.c. permeability obtained from Fig. 1, which appeared last month. Push-pull output transformers in which the d.c. effects cancel and interstage transformers which have the d.c. blocked from their windings are examples of the simple a.c. class.

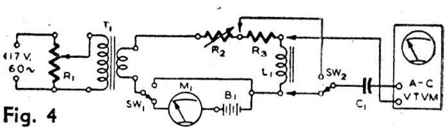

Fig. 4

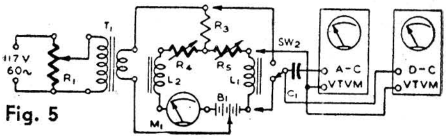

Fig. 5

R1—500-ohm, 100-w rheostat
R2—D.c. rheostat
R3—Non-inductive shunt resistor
R4,5—Two similar rheostats
C1—1-uf (or more) paper condenser
Sw1, 2—S.p.d.t. switches
L1—Iron-core inductance (under test)
L2—Iron-core inductance (like L1)
T1—Power transformer (heavy duty)
M1—D.c. milliammeter for range needed
B1—Battery, adjustable-voltage with center tap

Most iron-core inductance windings carry both a.c. and d.c. simultaneously—a.c. superimposed on d.c. As either of these may be varied in magnitude it is easy to see there would be an almost endless number of conditions, each resulting in a different inductance. The inductance rating of any device is accurate *only when the test conditions are the same as the normal load conditions.*

Curves may be prepared showing the a.c. flux density (B_{max-ac}) versus a.c. permeability (μ_{ac}) for various values of d.c. in the winding. Such curves prepared from test data on a special test core are called *incremental permeability* curves.

Due to the factors explained in connection with d.c. magnetization curves as well as other factors—eddy-current insulation, stacking factors, core shapes and sizes, and other characteristics of laminations — separate permeability curves are needed for each core design. The curves, when prepared from data obtained directly from a definite working design, using a specified steel or alloy, are called *apparent permeability* curves (μ_a). They indicate the actual permeability (not theoretical) which the design appears to have under selected working conditions.

An air gap is seldom used when the inductance is used only on a.c. except in such devices as fluorescent lamp and sunlamp ballasts. Lamp ballast design

SYMBOLS	ENGLISH UNITS	C.G.S. UNITS
M.M.F. (MAGNETO MOTIVE FORCE)	$=NI=R\emptyset$ (IN AMPERE TURNS)	$=0.4\pi NI=R\emptyset$ (IN GILBERTS)
R (RELUCTANCE)	$=\frac{MMF}{\emptyset}=\frac{NI}{\emptyset}=\frac{l}{3.19\mu A}=\frac{1}{P}$ 0.313 FOR 1 CU. IN. OF AIR	$=\frac{MMF}{\emptyset}=\frac{0.4\pi NI}{\emptyset}=\frac{l}{\mu A}=\frac{1}{P}$ 1. FOR 1. CU. CM. OF AIR
$\emptyset$ (MAXWELLS, FLUX, OR LINES OF FORCE IN ANY MATERIAL)	$=\frac{NI}{R}=\frac{3.19\mu NIA}{l}=\frac{MMF}{\frac{l_s}{3.19\mu A_s}\ \frac{l_a}{3.19A_a}}$	$=\frac{0.4\pi NI}{R}=\frac{0.4\mu\pi NIA}{l}=\frac{MMF}{\frac{l_s}{\mu A_s}+\frac{l_a}{A_a}}$
$\emptyset$ (SAME AS ABOVE BUT FOR AIR)	$=\frac{3.19NIA}{l}=\frac{NIA}{.313l}$	$=\frac{0.4\pi NIA}{l}$
P (PERMEANCE)	$=\frac{\emptyset}{MMF}=\frac{\emptyset}{NI}=\frac{3.19\mu A}{l}=\frac{1}{R}$	$=\frac{\emptyset}{MMF}=\frac{\emptyset}{0.4\pi NI}=\frac{\mu A}{l}=\frac{1}{R}$
NI (AMPERE TURNS FOR ANY MATERIAL)	$=\frac{H\emptyset l}{BA}=\frac{\emptyset l}{3.19\mu A}$ =AMPERES X TURNS	$=\frac{H\emptyset l}{0.4\pi BA}=\frac{\emptyset l}{0.4\pi\mu A}$ =AMPERES X TURNS
NI (AMPERE TURNS FOR AIR)	$=\frac{\emptyset l_a}{3.19A}$	$=\frac{\emptyset l_a}{0.4\pi A}$
l (LENGTH-l_s=STEEL-l_a=AIR	=INCHES=CM X .3937=2.54 CM	= CM=INCHES X 2.54=39 INCHES
A (AREA)	=SQ.IN=SQ.CM. X .155=6.45 SQ.CM.	= SQ.CM=SQ.IN. X 6.45=.155 SQ.IN
B (NORMAL INDUCTION IN ANY MATERIAL)	$=3.19\mu H=\frac{\emptyset}{A}=\frac{M.M.F.}{\frac{l_a}{3.19}+\frac{l_s}{3.19\mu}}$ = MAXWELLS/SQ.IN=GAUSSES X 6.45	$=\mu H=\frac{\emptyset}{A}=\frac{MMF}{l_a+\frac{l_s}{\mu}}$ = GAUSSES = MAXW./SQ.CM.=MAXW./SQ.IN X 0.155
B (MAGNETIC INDUCTION IN AIR)	$=3.19H=\frac{\emptyset}{A}$=MAXWELLS PER SQ.IN	$=H=\frac{\emptyset}{A}$= GAUSSES
H (MAGNETIZING FORCE)	$=\frac{NI}{l}=\frac{B}{3.19\mu}$=NI PER INCH LENGTH =OERSTEDS X 2.02	$=\frac{0.4\pi NI}{l}=\frac{B}{\mu}$=OERSTEDS=GILBERTS/CM LENGTH = NI PER IN. LGTH X 0.495
μ (PERMEABILITY FOR ANY MAT'L)	$=\frac{B}{3.19H}$	$=\frac{B}{H}$
μ (FOR AIR)	=1	=1
μ_a (APPARENT AC PERMEABILITY)	$=\frac{10^8 lL_a}{3.19N^2AK_1}$	$=\frac{10^8 lL_a}{0.4\pi N^2AK_1}$
La (APPARENT INDUCT. IN HENRIES	$\frac{3.19N^2\mu_a AK_1}{10^8 l}=\frac{N^2}{10^8\left(\frac{l_s}{3.19\mu_a A_s}+\frac{l_a}{3.19A_a}\right)}$	$=\frac{0.4\pi N^2\mu_a AK_1}{10^8 l}=\frac{0.4\pi N^2}{10^8\left(\frac{l_s}{\mu_a A}+\frac{l_a}{A_a}\right)}$

MISC. FORMULAE

$$L_a=\sqrt{\frac{Z^2-R_a^2}{4\pi^2 f^2}}=\frac{0.159\sqrt{Z^2-R_a^2}}{f}=\frac{X_L}{2\pi f}\ \text{OR, IF } R_a \text{ IS SMALL}=\frac{0.159Z}{f}$$

$$B_{ac}=\frac{10^8 E_{rms}}{4.44fANK_1}\quad E_{rms}=\frac{4.44N\emptyset_{max}}{10^8}\quad \emptyset_{max}=\frac{10^8E_{rms}}{4.44fN}\quad N=\frac{10^8E_{rms}}{4.44f\emptyset_{max}}=\frac{10^8E_{rms}}{4.44fAB_{ac}K_1}$$

$Z=\sqrt{X_L^2+R_a^2}$ $X_L=2\pi fL_a$ Z=IMPEDANCE IN OHMS f=CYCLES/SEC. π=3.1416 Ra=APPARENT RESTANCE IN OHMS X_L=INDUCTIVE REACTANCE IN OHMS K_1=STACKING FACTOR

Symbols and equivalent English and C.G.S. units of common magnetic terms and formulas.

(Continued on page 72)

must permit sufficient current to flow through the ballast for normal operation, make available enough starting voltage, yet limit the current to a safe value at all times.

Most inductances having d.c. in the windings have an air gap in the magnetic circuit. This is to increase the apparent permeability over that available without an air gap. The length of air gap which results in highest permeability and likewise highest inductance for the particular current conditions in the windings is called the *optimum air gap.*

Optimum air gap may be computed by proper application of the normal d.c. magnetization curve and the incremental permeability curve for a given steel and core. The procedure is rather lengthy and will not be presented here. The average experimenter would probably find it faster to use a test circuit and obtain apparent inductance, apparent permeability, and optimum air gap simultaneously.

Circuits suitable for measuring inductance, determining apparent permeability and optimum air gap, are shown in Figs. 4 and 5. The Fig. 4 circuit is suitable for low and zero direct current. D.c. saturation of the transformer core is eliminated with the Fig. 5 circuit but the circuit has the disadvantage of requiring two similar chokes.

In either circuit the d.c. is first adjusted to the normal working condition. R4 and R5, Fig. 5, must be so adjusted that no d.c. flows through R3. This can be determined by a d.c. v.t. voltmeter across R3. Sufficient a.c. voltage is applied to give the working values across