FERROXCUBE SLIDE RULE

DIRECTIONS FOR USE

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1. Introduction

In many cases the calculation of coil properties is a time consuming operation. The main reason is that these properties are governed by a considerable number of parameters, partly dependent on the winding and partly on the magnetic core.
Quite some experience is required to make a proper choice of these parameters in order to arrive at the most favourable coil design. In order to reduce the design time this slide rule has been developed, specially to carry out calculations of coils with ferroxcube cores. With the aid of this slide rule quick estimations may be made concerning the possibilities of magnetic circuits especially potcores. Its main purpose is to indicate the contribution of the core to the coil properties and to calculate the winding.

The slide rule has been provided also with normal slide rule scales log x, x, x^2 and x^3. (*13* up to and including *18*).
With the aid of these scales additional operations, such as the calculation of the D.C. copper losses are possible.

In the following examples the way of operating the slide rule for some current problems is explained.

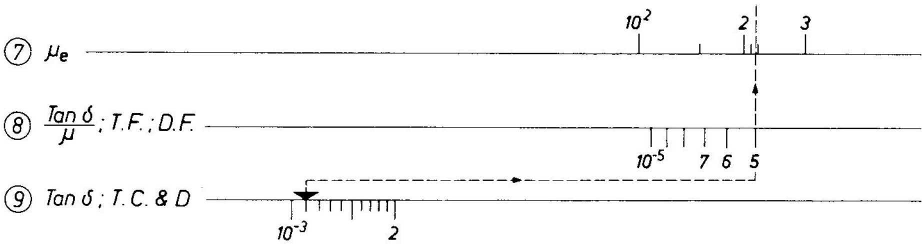
2. Determination of the max. permissible effective permeability (μ_e)

Assume that for the application in question the frequency of operation, the type of capacitor and the coil volume are fixed, then the appropriate core material can be chosen.
This fixes the max. values for the $\frac{\tan \delta}{\mu}$, the T.F. and the D.F.[1])
Depending on the fact which requirement is most severe (e.g. min. permissible quality factor, or max. permissible tan δ, max. permissible temperature coefficient or max. permissible disaccommodation).
The effective permeability may be determined as follows:

Unknown	Known	Put	Opposite	Read
μ_e	tan δ and $\frac{\tan\delta}{\mu}$	Yellow arrow on *8* or blue arrow on *8*	tan δ on *9* tan δ on *10*	μ_e on 7 opposite $\frac{\tan\delta}{\mu}$ on *8*
μ_e	T.C. and T.F.	Yellow arrow on *8* or blue arrow on *8*	T.C. on *9* T.C. on *10*	μ_e on 7 opposite T.F. on *8*
μ_e	D and DF 1 min - 24 h	Yellow arrow on *8* or blue arrow on *8*	D on *11* 2) D on *12*	μ_e on 7 opposite D.F. on *8*
μ_e	D and DF 10 min - 100 min	Yellow arrow on *8* or blue arrow on *8*	D on *9* 3) D on *10*	μ_e on 7 opposite D.F. on *8*

1) See Fxc handbook pages A.2.1., A.3.1., F.3.1. and F.5.1.
2) Scales *11* and *12* give the Disaccomodation in the period of 1 minute to 24 hours.
3) Scales *9* and *10* give the Disaccomodation in the period of 10 minutes to 100 minutes.

Example:



Given: Maximum permissible core loss is $\tan\delta = 1.1\ 10^{\ 3}$. — scale 9

Maximum losses of chosen core material $\frac{\tan\delta}{\mu} = 5\cdot 10^{\ 6}$ — scale 8

Reading: $\mu_e = 220$ — scale 7

3. Determination of the number of turns

To determine the number of turns N for a given inductance one of the following three data is sufficient. (See appendix)

a. Turns factor α

b. Inductance factor A_L

c. The combination of $\sum \frac{l}{A}$ and μ_e

Unknown	Known	Put	Opposite	Read
N	L and α	α on *4*	Arrow (1 mH) on *5*	N on *4* opposite L on *5* or N on *3* opposite L on *2*
N	L and A_L	Arrow on *3*	A_L on *1*	
N	L; $\sum \frac{l}{A}$ and μ_e	$\sum \frac{l}{A}$ on *6*	μ_e on *7*	

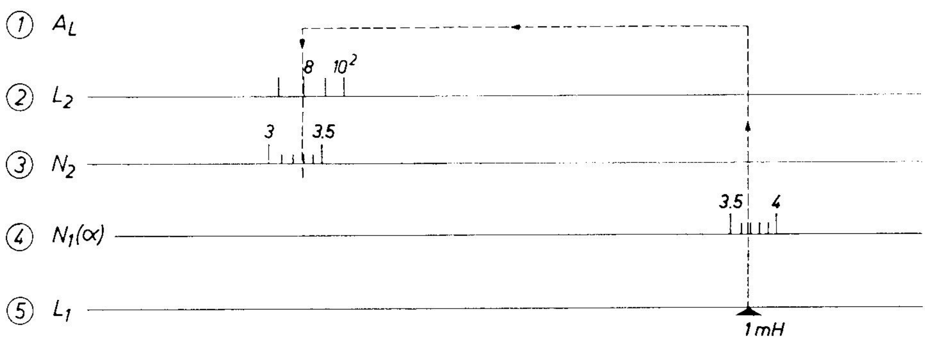
It goes without saying that the reverse operation, e.g. to determine the inductance L for a given number of turns is simply carried out by setting the slide rule in the same way as before and interchanging N and L in the first two and the last columns.

Conversion of $\sum \frac{l}{A}$ plus μ_e into α or A_L or the reverse and of α into A_L or the reverse may be carried out conveniently using the scales *1* up to and including *7*.

Unknown	Known	Put	Opposite	Read
α; A_L	$\sum \frac{l}{A}$ & μ_e	$\sum \frac{l}{A}$ on *6*	μ_e on *7*	α on *4* opposite arrow on *5* A_L on *1* opposite arrow on *3*
A_L	α	α on *4*	Arrow on *5*	A_L on *1* opposite arrow on *3*

For a number of cores the $\sum \frac{l}{A}$ is given below *8* on the slide.

Example: given: α = 36.8 scale *4*
L = 80 mH scale *2*
reading: N = 329 scale *3*



4. Determination of the type and size of winding wire

The choice of type of wire, solid or stranded, depends on the frequency for which the coil has to be developed.
The winding may be made in a single section or divided in two or more sections, depending on the frequency of operation and the inductance.
The table below scale *19* on the slide gives the winding areas A_{cu} for current types of coil formers.

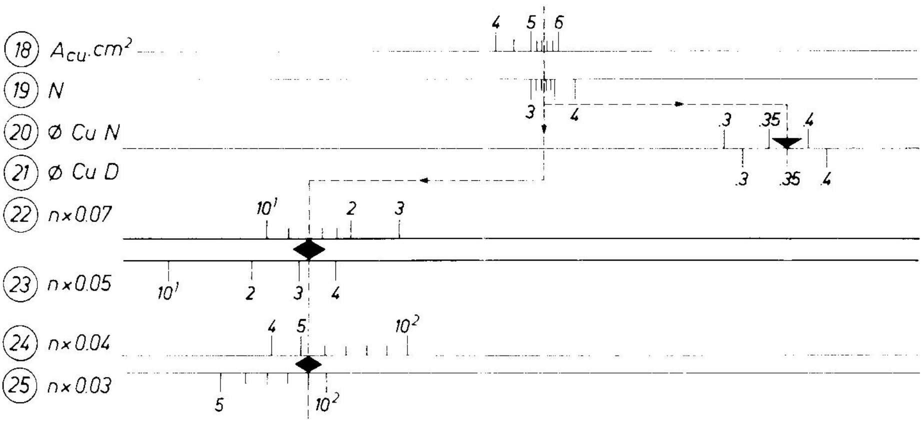
The wire size on scales *20* and *21* is indicated by the *nominal* diameter of the copper core. Scale *20* is for normal copper-enamel insulated wire: scale *21* copper wire with extra thick enamel insulation.
The scales 22 up to and including *25* indicate the number of strands for Litz wires of four different strand diameters e.g. 0.07; 0.05; 0.04 and 0.03 mm.

For a given number of turns N and winding area A the type of wire may be determined as given below

Unknown	Known	Put	Opposite	Read
Diameter of solid wire Number of strands Litz wire	N and A_{cu}	N on *19*	A_{cu} on *18*	solid wire below black arrow on *20* or *21* Number of strands opposite black arrows between *22*/*23* and *24*/*25*

Example: N = 329 A_{cu} = 0.55 cm² (1 section bobbin P30/19)

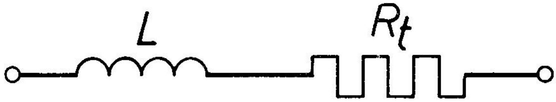
In this case the bobbin could be wound with
0.35 Cu N solid copper wire
or 0.35 Cu D heavy insulated solid copper wire
or 12 x 0.07 S.S.C. stranded wire
or 32 x 0.05 S.S.C. stranded wire
or 50 x 0.04 S.S.C. stranded wire
or 90 x 0.03 S.S.C. stranded wire



18 $A_{cu} \cdot cm^2$
19 N
20 Ø Cu N
21 Ø Cu D
22 n×0.07
23 n×0.05
24 n×0.04
25 n×0.03
4 5 6
3 4
.3 .35 .4
.3 .35 .4
10^1 2 3
10^1 2 3 4
4 5 10^2
5 10^2

APPENDIX

The slide rule has been set up using the design formules common to standard practice. It is assumed that an inductor having losses may be represented by the series connection of an ideal inductance L without losses and a resistance R_t standing for the total losses. The most important requirements to be met for an inductor are:



a. the inductance: $L = \dfrac{0.4\,\pi \times N^2}{\dfrac{1}{\mu_e} \times \sum \dfrac{l}{A}}\, 10^{-8}$ Henry

For a given inductance L the required number of turns N may be calculated from the core data μ_e and $\sum \dfrac{l}{A}$.

However, it is more customary to calculate the number of turns from either:

1. the Turns factor α giving the number of turns for 1 mH: $N = \alpha \sqrt{L}$
   or
2. the Inductance factor A_L giving the inductance in nano Henry for 1 turn: $N = \sqrt{\dfrac{L}{A_L}}$

b. the temperature dependance of inductance expressed as

$$\text{Temperature Coefficient} = \frac{L_{T_2} - L_{T_1}}{L_{T_1}(T_2 - T_1)}.$$

The contribution of the core to the temperature dependance may be calculated from the Temperature Factor of the core material:

$$T.C = \mu_e \times T.F.$$

where $T.F. = \dfrac{1}{\mu_i^2}\,\dfrac{d\mu}{dT}$

c. The time dependance of inductance

The irreversible type of aging is not meant here, but the reversible contribution of the core to the total coil variability.

This contribution of the core is expressed as the Disaccommodation

$$D = \frac{L_{t_1} - L_{t_2}}{L_{t_1}} \times 100\,\%.$$

The core properties in this respect are specified as a Disaccommodation Factor

$$D.F. = \frac{\mu_{t_1} - \mu_{t_2}}{\mu_{t_1}^2 \times \log \dfrac{t_2}{t_1}}$$

The disaccommodation follows from

$$D = \mu_e \times D.F. \times \log \frac{t_2}{t_1}$$

When t_1 is chosen as 1 minute and t_2 as 24 hours this equation becomes

$$D = \mu_e \times D.F. \log 1440$$

At present for t_1 and t_2 more frequently 10 minutes and 100 minutes are chosen, making

$$D = \mu_e \times D.F.$$

d. The Quality Factor Q

When inductors are used in electrical filters their quality is usually expressed as the quality factor $Q = \frac{\omega L}{R_t}$

However for coil design this factor lends itself less well, since often the different components of the total losses have to be determined separately, and added afterwards to determine the total losses.

In the above formula these components cannot be added simply.

For this reason coil designers prefer the dissipation factor $\tan \delta_t$, which is the reciprocal of the quality factor,

$$\tan \delta_t = \frac{1}{Q} = \frac{R_t}{\omega L}$$

or even more simple $\frac{R_t}{L}$.

Now simple addition of the component loss parts is possible since

$$\frac{R_t}{L} = \frac{R_o}{L} + \frac{R_{ec}}{L} + \frac{R_d}{L} + \frac{R_h}{L} + \frac{R_r}{L} + \frac{R_e}{L} \ \Omega/H$$

or $\tan \delta_t = \tan \delta_o + \tan \delta_{ec} + \tan \delta_d + \tan \delta_h + \tan \delta_r + \tan \delta_e$

The losses may be separated in two groups:

a. The losses in the *winding*

$\frac{R_o}{L}$ or $\tan \delta_o$ representing the D.C. copper losses

$\frac{R_{ec}}{L}$ or $\tan \delta_{ec}$ representing the eddy current copper losses

$\frac{R_d}{L}$ or $\tan \delta_d$ representing the dielectric losses and the apparent loss increase caused caused by the presence of the stray capacity.

b. The losses in the *Core*

$\frac{R_h}{L}$ or $\tan \delta_h$ representing the hysteresis losses

$\frac{R_e}{L}$ or $\tan \delta_e$ representing the eddy current core losses

$\frac{R_r}{L}$ or $\tan \delta_r$ representing the residual losses

As a rule the maximum quality factor is realised when the sum of the copper losses is made equal to the sum of the core losses. It should be noted that the core losses are

proportional to the effective permeability μ_e, whereas the copper losses are inversely proportional to it.
In a good coil design care is taken to avoid the dielectric losses and the hysteresis losses; furthermore by the proper choice of the winding wire and the core material the eddy current losses are reduced to the minimum.

In practice the choice of the value for the effective permeability has to be a compromise.

It will depend on the fact that either the requirement for the temperature coefficient of inductance or the requirement for the quality factor dominates.