# MEASUREMENT OF INDUCTANCE
# Some Problems and their Solutions

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The measurement of inductance can still pose a problem in this age of digital instrumentation and automation. Most people who are concerned with component testing have very little trouble with resistance or capacitance measurement. But quite often the measurement of inductance presents problems which cannot be overcome with the usual type of universal bridge. Numerous observations made in laboratories and test departments are furnishing ample proof that important fundamentals of science of electronic measurements are apt to slip our minds in spite of, or perhaps because of, technical progress. This article explains the reason for the difficulties and provides some guidelines for their removal.

Inductors are impure elements and have significant resistance at measurement frequencies and also core loss, which absorbs energy from the source. Due to these unavoidable losses, an inductor can be thought of as a pure resistance in


Fig.

series or shunt with a lossless inductance (Fig. 1). The series circuit meets our expectations best, especially if the losses are mainly caused by resistance of the winding. This is the case particularly with air-core coils. If there is a solid core, the losses with increasing frequency no longer result from the copper resistance but due to losses in the core. It is a good practice to consider them shunted across inductance.

The inductance values of the equivalent series circuit are not the same as in the equivalent shunt circuit. The conversion of the values in the one circuit into those valid in the other can be made using familiar equations, provided the equivalent loss resistances 'Rp' and 'Rs' are known. However, it is much simpler to calculate with the value of the coil Q:

$$Q = \frac{wL_s}{R_s} = \frac{R_p}{wL}$$

The parallel inductance then is

$$L_p = L_s \left[ I + \frac{I}{Q^2} \right]$$

and the series inductance is

$$L_s = \frac{L_p}{I}$$

I

As can be seen, the difference between the two inductances decreases as the 'Q' increases. Of course, if Q of the inductor at the test frequency is sufficiently high it matters little how the inductor is measured as the relationship between the series and parallel values is given by:

$$\frac{\text{Parallel value of Inductance}}{\text{Series value of Inductance}} = \frac{I + Q^2}{Q^2}$$

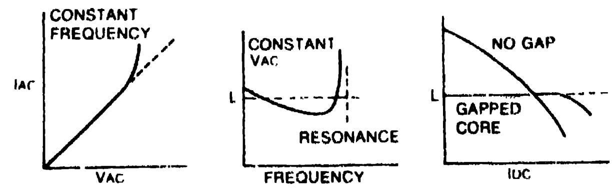


Fig. 2

The difference in value is only one per cent if Q equals 10 and about four per cent if Q equals 5. It is when Q is low that the difference is large; when Q equals one the ratio is 2 to1. For this reason, a distinction between the parallel and series inductances need be made only if the inductor has a low Q value at the measurement frequency.

Further, it happens in practice that most inductance bridges enable inductance measurements to be made only in the audio range where the Q of inductor is mainly governed by the winding resistance and may be very low. The results must be reckoned with in the overlapping region of the series and shunt arrangement of measurement facility in the bridges. The popular Hay bridge arrangement, normally used by manufacturers of power chokes and transformers, measures inductors under shunt conditions. The Maxwell bridge measures the inductor as a series arrangement (Fig. 2).

Inductors are also non-linear, and a plot of current

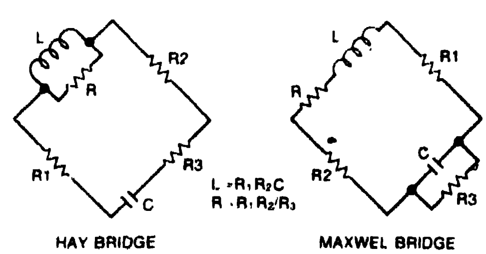


Fig. 3

against voltage at a constant frequency would not be a straight line. In a typical inductor the line would also be bent if the frequency was varied while the voltage remained constant, or if a direct current component was varied while all other conditions remained the same. These variations are illustrated in Fig. 3.

Non-linearity is mainly due to the magnetic core of the inductor. Air-cored inductors are usually very linear up to the frequency at which the effects of distributed capacitance become significant. The changes can then be relatively rapid as the capacitance effect is predominant.

Non-linearity of magnetic core permeability is due to the complex way in which the magnetism of the crystal structure of basic material varies as the magnetising field is changed. In general, if the magnetic circuit is diluted with non-magnetic material, such as air or neutral material in the magnetic circuit, then the non-linearity is reduced.

Non-linearity of permeability is the principle factor which makes it imperative for an inductor to be measured under specified conditions. It is the failure of operators to realise this point, or perhaps the failure of someone to adequately specify the conditions, that mostly causes disagreement between two inductance values in a batch of similar inductors.

Non-linearity has other effects when the inductor is used in an actual circuit. Suppose, for example, the inductor is to be used in a filter. It can happen that the inductance may be different in the circuit from the test conditions, owing to different operating currents. This may affect the filter performance. Again, a filter intended to reduce harmonic distortion may actually increase the distortion owing to the non-linearity of the core. Cross talk or intermodulation is another possible result of non-linearity. All this stresses the need to control the measuring conditions of inductors with magnetic cores.

Inductance values usually vary with the following parameters:

1. Alternating voltage level.
2. Direct current component through inductor.
3. Frequency of measurements.
4. Capacitance and inductance of connecting leads.
5. Mode of measurement.
6. Previous magnetic and mechanical conditions of the inductor.

Many inductor specifications are vague so that, in the absence of instructions to the contrary, any bridge is used for the measurement and the result assumed to be a true value even under operating conditions. If the inductor manufacturer and user happen to adopt approximately the same measurement technique then they will be fortunate enough to be in agreement. But the user may be disappointed if the inductor does not fit his circuit application in practice though it apparently should in theory. A proper specification would overcome the discrepancies. □