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Accurate Measurement of 'Q' Factor of an Inductive Coil Using a Modified Maxwell Wein Bridge Network

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Abstract: The Q factor of a coil can be measured by measuring accurately the inductance and effective resistance of the coil for a specific signal. The inductance of an inductive coil is generally measured by usual inductive circuit like Maxwell-Wein Bridge, Hay Bridge etc. which suffer from error due to stray capacitance between bridge nodal point and ground and stray inductance of the inductive coil. The conventional Wagner Earth Technique is not suitable for continuous measurement. In the present paper, a modified operational amplifier based Maxwell-Wein Bridge measurement technique has been proposed in which stray capacitance and stray inductance are minimized. The experiment is done for different value of known inductance & Q factor for a specific signal. The linear characteristic with a good repeatability, linearity and variable sensitivity has been described. *Copyright © 2009 IFSA.*

Keywords: Modified Maxwell – wein bridge, Q factor, Inductive transducer, Operational amplifier, Bridge sensitivity

1. Introduction

The accurate measurement of Q factor of an inductive coil is important in many aspects of instrumentation such as inductive transducer design etc. [2, 5, 8, 9, 14]. The Q factor may be measured by accurate measurement of inductance and effective resistance of the coil for a particular signal frequency. Also, an inductive transducer used for different process variable as level, flow, pressure etc. exhibits change of inductance proportional to the change of process variable being measured. This change of Q factor is generally very small and may be sometimes be comparable with the Q factor of stray inductance of the coil. The measurement of Q factor of an inductor or an inductive transducer is required to make with high accuracy. There are different bridge measurement techniques [1, 2, 5, 8, 9, 16, 18] for measurement of inductance but Maxwell-Wein Bridge is a very sensitive one for such measurement. The measurement error due to the stray capacitance between bridge nodal points and ground and stray inductance of the coil with this bridge technique may be minimized by using Wagner-Earth technique [1, 2, 5, 8, 9, 14, 16, 18] with screened bridge components and lead wires. One disadvantage of this technique may be requirement of several repetitions of bridge balance and Wagner Earth balance for each observation.

A modified approach of balancing technique of AC Wheatstone bridge network has been reported by E. Takagishi [17], whereas D. Morioli et. al. [20] and P. Holmberg [10] has proposed self-balancing technique to achieve highly accurate measurement. T. L. Zapf [19] proposed the calibration method for measurement of inductance using Maxwell Wein Bridge.

In the present investigation, a low cost modified operational amplifier based Maxwell-Wein Bridge Technique with adjustable bridge sensitivity has been utilized to measure the Q factor of inductive coil. This technique minimizes the effect of stray capacitance without use of Wagner-Earth method. With this method, the bridge nodal points and the bridge output lead wires are both kept at virtual ground potential so that the effect of stray capacitance between the bridge output lead wires and also between any outputs lead wire and ground may always be assumed to be negligible. The bridge-balanced equation of the modified Maxwell-Wein Bridge network is also identical to that of conventional Maxwell-Wein Bridge network. Thus continuous measurement may be possible by using this modified Maxwell-Wein Bridge network. Moreover, this technique also provides an additional bridge sensitivity factor adjustment by linear potentiometer.

In the present paper, the experimental work was conducted with series combination of known inductance and known resistance instead of actual inductive coil, and the observed calibration curve and percentage error curve in terms of the bridge components for different values of bridge sensitivity factor, as obtained, are reported. Moreover, the performance of the bridge network for a particular inductor has been compared with that of the conventional Maxwell-Wein Bridge network developed by H. Tinsley & Co. England.

2. Method of Approach

A general AC Wheatstone bridge network is modified as shown in the Fig. 1, where two very high gain operational amplifiers A_1 and A_2 are connected with the bridge network and the non-inverting terminal connected to the circuit common or ground.

This enables the bridge output nodal points B and D to be almost at the same potentials with respect to the ground and hence the effect of stray capacitance that will exist between them and also between them and ground and stray inductance of the inductive coil may be assumed to be minimized.

Since B and D are at virtual ground, so for the sinusoidal supply voltage $V = V_m \, Sin\omega t$, the currents through the bridge impedances Z_1, Z_2 , Z_3 and Z_4 are respectively given by,

$$I_1 = \frac{V}{Z_1} \ , \ I_2 = \frac{V}{Z_2} , \ I_3 = \frac{V_1}{Z_3} \text{ and } I_4 = \frac{V_1}{Z_4} , \tag{1}$$

where V_1 is the output voltage of the operational amplifier A_1 .

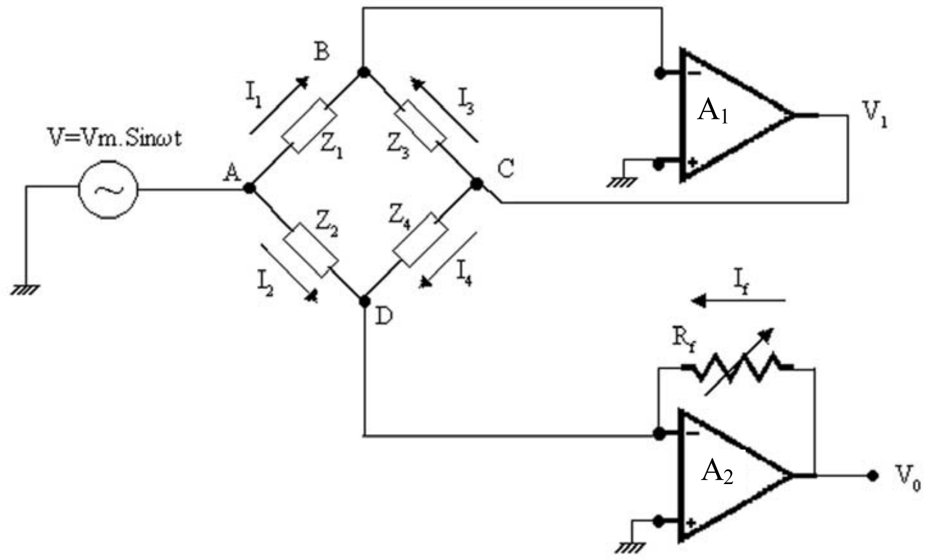

Fig. 1. Modified ac Wheatstone bridge network.

If V_0 be the output voltage of the operational amplifier A_2 then the current through its feedback resistance is given by

$$I_f = \frac{V_0}{R_f} \tag{2}$$

From the Kirchhoff's current law,

$$I_1 + I_3 = 0 \tag{3}$$

And

$$I_2 + I_4 + I_f = 0. \tag{4}$$

From the equation nos. (1) and (3), we get,

$$\frac{V}{Z_1} + \frac{V_1}{Z_3} = 0 \text{ Or } V_1 = -\left(\frac{Z_3}{Z_1}\right)V. \tag{5}$$

From the equation nos. (1) and (4) we get,

$$\frac{V}{Z_2} + \frac{V_1}{Z_4} + \frac{V_0}{R_f} = 0 \tag{6}$$

From the equation nos. (5) and (6) we get,

$$V_0 = \frac{R_f}{Z_1\, Z_2\, Z_4}\left(Z_2\, Z_3 - Z_1\, Z_4\right) V \tag{7}$$

At balance condition of the bridge, $V_0 = 0$.

i.e.,

$$Z_2\ Z_3 = Z_1\ Z_4 \text{ or } \frac{Z_1}{Z_2} = \frac{Z_3}{Z_4} \tag{8}$$

This balance condition is identical with that of the conventional bridge network.

In the case of inductor or an inductive transducer, the inductance is generally measured by Maxwell Wein Bridge network. The measurement error due to the effect of stray capacitance between the bridge nodal points and between the lead wires and stray inductance of the inductive transducer may be minimized by using modified networks as shown in Fig. 2.

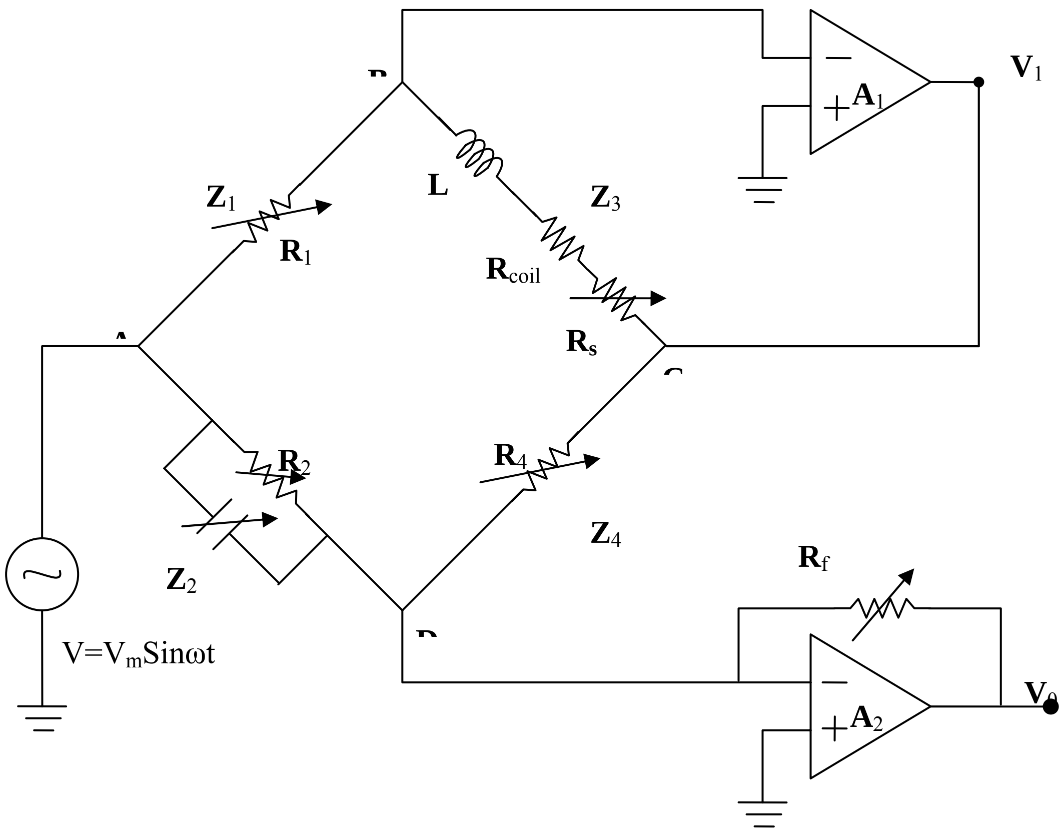

Fig. 2. Modified Maxwell Wein Bridge network.

For the modified Maxwell bridge network as shown in Fig. 2,

$$Z_1 = R_1,\ Z_2 = \frac{R_2}{1 + j\omega CR_2},\ Z_3 = R_3 + j\omega L,\ Z_4 = R_4 \tag{9}$$

$$R_3 = R_s + R_{coil}\ , \tag{10}$$

where R_s is the resistance connected in series with inductor and R_{coil} is the effective resistance of the inductive coil.

Hence from the equation no. (7), the bridge output voltage is given as

$$V_0 = \frac{R_f}{R_1\ R_2\ R_4}\left[\left(R_2\ R_3 - R_1\ R_4\right) + j\omega R_2\left(L - CR_1R_4\right)\right]\ V \tag{11}$$

If the bridge is balanced, then $V_0 = 0$.

i.e.,

$$\frac{R_f}{R_1\ R_2\ R_4}\left[\left(R_2\ R_3 - R_1\ R_4\right) + j\omega R_2\left(L - CR_1R_4\right)\right]\ V = 0 \tag{12}$$

Equating real part and imaginary part of the above equation, we obtain the following equation

i.e.,

$$R_2R_3 - R_1R_4 = 0 \tag{13}$$

and

$$L - CR_1R_4 = 0 \tag{14}$$

Now from equation (13), we get

$$R_3 = \frac{R_1R_4}{R_2} \tag{15}$$

$$R_3 = R_s + R_{coil} \text{ and } R_{coil} = R_3 - R_s \tag{16}$$

and from equation (14)

$$L = R_1R_4C \tag{17}$$

Now the Q factor of the coil

$$Q = \frac{\omega L}{Rcoil}, \tag{18}$$

where

$$\omega = 2\Pi f \tag{19}$$

and f is known for particular bridge excitation voltage.

Therefore, the Q factor of the inductor for a particular frequency of bridge excitation voltage can be easily measured from equation (16, 17, 18 and 19).

3. Experimental Results

The experiments were performed using modified Maxwell Wein Bridge setup with a stabilized sinusoidal excitation signal at 1000 Hz and with known variable inductors, decade capacitors, decade resistors and potentiometers as shown in the Fig. 2, at a selected value of R_f. The CRO and $4\frac{4}{5}$ digit TX3 true RMS digital multimeter were used as the detector and the measuring unit respectively. The bridge components of network are the standard laboratory equipment with the following specification.

R_1, R_2, Rs, R_4 = Variable decade resistance box (100 kΩ, 10KΩ, 1 KΩ, 100 Ω, 10 Ω, 1 Ω).

Make: PACIFIC; TYPE: AER 35
C = Variable decade capacitance box (1 µF, 100 KPF, 1 KPF, 100 PF, 10 PF) Make: PACIFIC; TYPE: TEC200
R_f = 20 KΩ, 3 W, wire wound potentiometer
L = Variable decade inductance box, (0.1, 0.01, 0.001 mH decades).

The initial bridge balance condition was obtained with a small value of L for a selected value of R_f by adjusting the variable resistance potentiometer and variable capacitor C. Then the same procedure is done for different value of L and the values of R_1, R_2, R_s, R_4 and C is measured. The experiment is repeated for different values of bridge sensitivity resistance R_f. The experimental results of three sets of experiments were taken for three different orientations of the connecting wires. The calibration curve and the percentage error curve of Q factor for different values of inductance and bridge sensitivity factors are shown in Fig. 3 and Fig. 4. respectively.

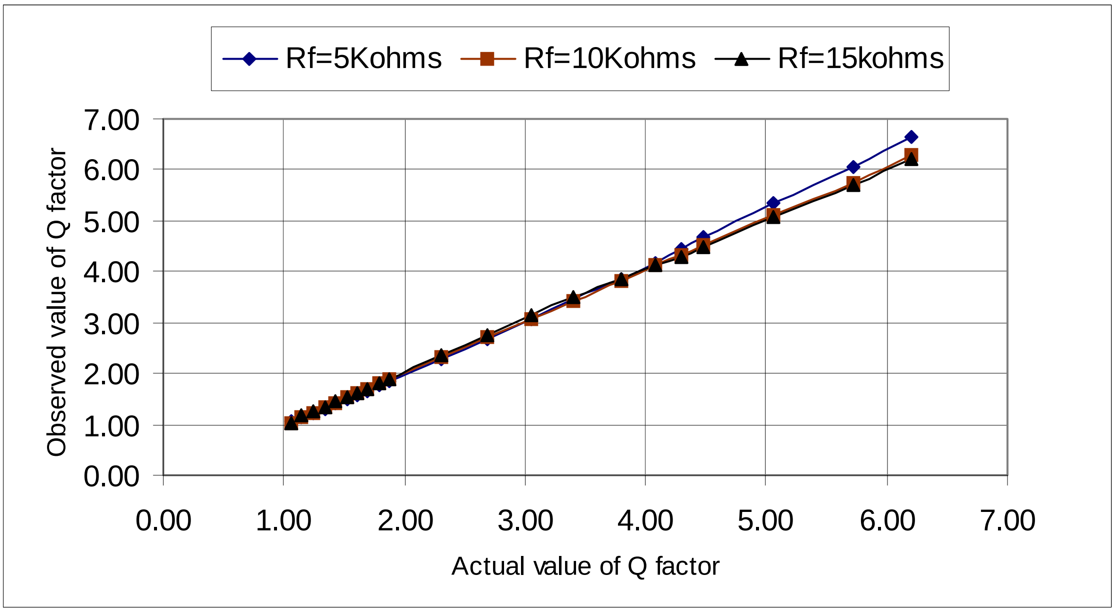

Fig. 3. Calibration curves of Q factor for different values of bridge sensitivity factor resistance [R_f].

5. Discussion

The experimental graphs as shown in Fig. 3 are found to have quite good linearity with the variable of Q factor of inductor and % deviations are within tolerable limit as shown in Fig. 4. Moreover during experimentation it was found that the same results were obtained for different orientation of connecting wires with respect to the ground and observer. Hence the results appear to have minimum error due to stray capacitance and inductance. The same experimental results were also obtained when the experiment was repeated several times.

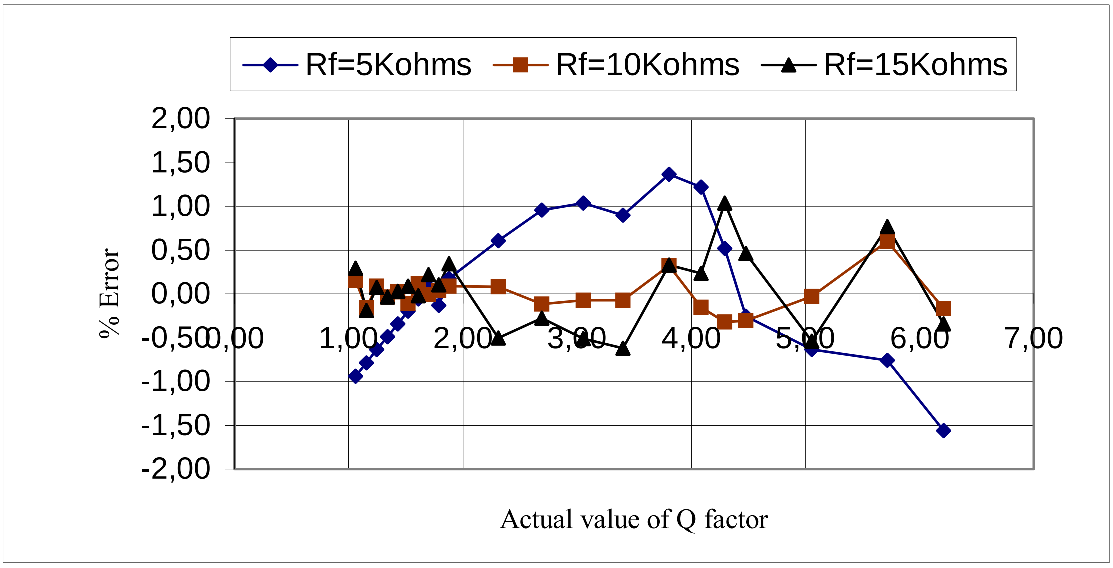

Fig. 4. % Error curve of Q factor for different values bridge sensitivity factor.

Thus the modified Maxwell Wein Bridge, as proposed in the present investigation, may be more effectively used for accurate measurement of Q factor of any inductor or inductive transducer in conventional circuits.

To obtain optimum sensitivity, the bridge arms impedances should be selected to be nearly identical, like all other bridge networks. Before connecting the ground to the common terminal of the network, care was taken to ensure that the ground wire was at nearly zero potential so that the high ground potential did not damage the *ICs*. The bridge balance condition was found not to be disturbed due to any change of orientation of the lead wires. The calibration curves of Fig. 3, and percentage deviation curves of Fig. 4 show that the effect of the stray capacitance and inductance may be assumed to be very small. The sensitivity of the bridge network may be varied by varying the potentiometer resistance R_f as explained in equation no (12).

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Guide for Contributors

Aims and Scope

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