

## Design and Measurement of the nH Level Mutual Inductor

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**Abstract** — A nH level mutual inductor has been designed and used as the standard impedance for measuring the equivalent inductance of current shunts. A method has also proposed to measure the mutual inductance against the ac voltage standard and current standard at frequencies up to 200 kHz.

### I. INTRODUCTION

The development of high frequency power standards need to know the phase error of ac shunts very precisely . In recent years, different kinds of ac shunts are developed to meet the needs for the accurate measurements of ac current. The phase angle error of high current shunts is usually calibrated against shunt with known phase angle in the step-up procedure [1].

The resistances of the high current shunts are normally in the mΩ level, and the reactance of the shunts which is generated by the equivalent inductance as the dominate part at high frequency. The equivalent inductance of high current shunt can be directly measured against the standard impedance, so that the phase error can be determined [2]. We need a nH level inductance standard to determine the inductance of the shunts.

### II. MUTUAL INDUCTOR

A current  $I_1$  in a primary coil produces a proportional magnetic flux which threads a secondary coil and the mutual inductance  $M$  can be expressed as:

$$M = \frac{\Psi_{12}}{I_1} \quad (1)$$

where the  $\Psi_{12}$  is the linked flux,  $M$  is termed the mutual inductance of the coil assembly. The mutual inductance is usually determined by size and geometry of the windings, the relative position between the primary and secondary winding, and the turns of the windings.

### III. DESIGN OF THE MUTUAL INDUCTOR

The capacitance from the windings will cause the imperfection of the mutual inductor, as shown in Fig.1 (a). Considering the existence of the capacitance and the leakage inductance and wire resistance from the primary winding and secondary winding, the mutual inductor can be expressed as:

$$\begin{cases} M_{IM} = M - C_{13}R_1R_2 + M\omega^2 \left( (C_{12} + C_{14})L_1 + (C_{23} + C_{34})L_2 + C_{13} \times \frac{(L_1 + M)(L_2 + M)}{M} \right) \\ R_{RE} = M\omega^2 \left( (C_{12} + C_{14})L_1 + (C_{23} + C_{34})L_2 + C_{13} \times \frac{(L_1 + M)(L_2 + M)}{M} \right) \end{cases} \quad (2)$$

where  $M_{IM}$  is the image part of the mutual inductor, and the  $M_{RE}$  is the real part of the mutual inductor. According to the equation (2), there is a fractional alteration in the apparent in-phase secondary and a fractional change in the phase angle of the  $90^\circ$ .

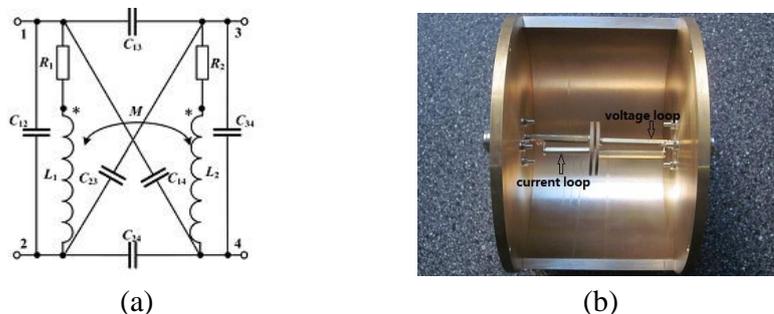


Fig.1 structure and the equivalent circuit of the mutual inductor

The design of mutual inductor is shown in Fig.1 (b). The primary winding and the secondary winding are both one turn rectangle design used as the current input loop and voltage loop with an N-type connector.

#### IV. MEASUREMENT OF THE MUTUAL INDUCTOR

Capacitive effect, eddy current losses, leakage and dielectric losses in the insulation, and the real resistance can be the contributions to departure from an ideal  $90^\circ$ . In this case, the departure can be represented by the small resistance  $r$ , which is known as the impurity of the mutual inductance. The phase defect of the mutual inductor is expressed as  $r/\omega M_{IM}$ .

The phase defect of the mutual inductor is measured to be within 0.02 rad at frequencies from 20 kHz to 200 kHz by meaning of the Lock-in Amplifier (LIA). The mutual inductance can be measured against a current shunt  $R_S$  with known ac resistance so the mutual inductance can be determined. The mutual inductor is measured at frequencies from 20 kHz to 200 kHz, and the results are given in table I.

Table I  
MEASUREMENT RESULTS OF THE MUTUAL INDUCTANCE IN NH

$f$ (kHz)	20	50	75	100	150	200
M	3.488	3.436	3.429	3.423	3.420	3.419

#### V. CONCLUSION

The phase defect of the mutual inductor will cause the departure from an ideal  $90^\circ$ , and the mutual inductor can be measured by comparing with current shunt and calibrated against the voltage standard and current standard. The mutual inductor is designed to be used as the impedance standard at high frequencies.

#### REFERENCES

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