Design of an Integrating Meter for Magnetic Flux Measurement

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***Abstract*-This is primarily a tool designed for use in measurement and industrial systems. This flux meter can measure total flux, from which the magnetic field strength and flux density, and various other parameters can be determined. This meter can be immensely valuable for accurate speed control of machines at low speed, for measurement of persistent current in a superconducting magnetic ring and for measuring the stray magnetic field around the transformers. Standard flux indicators presently in use are only providing a qualitative idea of magnetic flux levels which may not be sufficient to provide the optimum conditions for carrying out various magnetic inspections. Thus this meter is designed to measure the magnetic flux density whose value can be too low or high and can also measure the flux density in any direction.**

Keywords—*Integrating Flux meter, Magnetic Flux meter, Stray flux, Persistent current, Magnetic flux density.*

I. INTRODUCTION

Magnetic flux, is a measure of the magnetic field strength existing on a two dimensional surface, such as one side of a magnet. Usually, a cluster of vectors attached to a geometrical abstract surface is referred to as magnetic flux, wherein each vector will intersect a separate point on the abstract surface as in [1]. The definition of surface integral relies on splitting the surface into small surface elements. Each surface element is associated with vector dS, whose magnitude is equal to the area of the element, and whose direction is orthogonal to the element and pointing outwards.

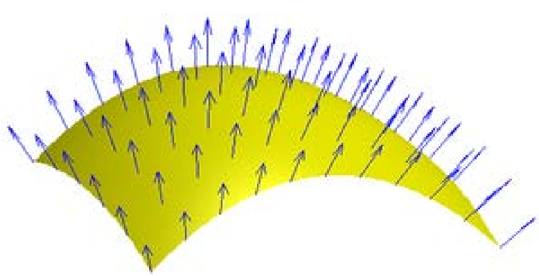

Fig. 1 A Vector Field of Normal to a Surface

More generally, the magnetic flux at any angle to a surface is defined by a scalar product of the magnetic field and the area element vector as in [2]. The direction of the magnetic field vector B is by definition from the south to the North Pole of a magnet.

Outside of the magnet, the field lines will go from north to south. The magnetic flux through a surface *S* is defined as the integral of the magnetic field over the area of the surface,

$$\Phi_m = \iint_S B.dS. \quad (1)$$

Where,

Φ_m is the magnetic flux

B is the magnetic field

S is the surface (area)

. Denotes dot product

d**S** is an infinitesimal vector, whose direction is the surface normal, and whose magnitude is the area of a differential element of *S*.

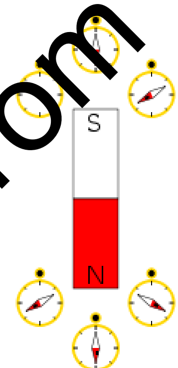

Fig. 2 Representation of a Magnetic Field which points Away From a Magnet's North Pole And towards Its South Pole

Magnetic flux may also be defined as path integral of magnetic potential,

$$\Phi_m = \oint_{\Sigma} A.dl. \quad (2)$$

Where,

$\sum$ is a surface bounded by the closed contour

A is the magnetic potential

dl is an infinitesimal vector element of the contour $\sum$

If the magnetic field is constant with a value '*B*' and the surface is a planar surface of area '*A*', then the above formula simplifies to,

$$\Phi_m = BA \cos\theta. \quad (3)$$

Where,

θ is the angle between the surface normal to *S* and B.

The magnetic flux is usually measured with a flux meter. The flux meter contains sensing or measuring coils and electronics that evaluates the change of voltage in the measuring coils to calculate the magnetic flux. This flux meter employs only the electronic circuits and Integrators are used in this magnetic measurement because of the physical relationship between magnetic flux and the coils of wire. Also, the usage of only electronic circuits facilitates very less drift and low cost of the instrument.

II. Important features of this flux meter

The instrument's low drift improves productivity with fewer adjustments. It has many features to enhance throughput like faster settling times. Further, it also recovers quickly from reading reset to starting a new reading cycle. Using this, both a positive and negative peak can be captured from the same pulse. The high resolution of this flux meter is reinforced by a low noise floor. A configurable filter helps to keep the readings quiet. It is quick to setup and easy to use. This flux meter protects the operator and surrounding area from electric burn or shock, excessive temperature, spread of fire from the instrument and mechanical hazards. Drift is the most noticeable and often the largest source of error in integrating flux meters. Drift is a slow change in reading when no change in flux exists. It is caused by any small error voltage at the integrator input. This flux meter has very low drift.

Magnetic inspection often calls for the use of a specified level of magnetic flux within steel components. Standard flux indicators only provide a qualitative idea of magnetic flux levels which may not be sufficient to guarantee the optimum conditions for carrying out magnetic inspection. If the magnetic flux level is too low, then the defects may be overlooked, if the flux is too high then spurious indications may occur in a conventional flux meter. This flux meter has been produced to measure the magnetic flux density just below the surface whose value can be too low or high.

Most magnetic field meters and gauss meters only measure the level of magnetism outside components under inspection. Yet it is the value of magnetic flux density within components which determine whether or not Magnetic Particle Inspection can be successfully carried out. Hence this flux meter is designed to measure the flux density in any direction.

The integrator reacts continuously to the changing input to give an accurate area measurement. It is inconvenient to use this relationship directly for DC measurements because the voltage disappears as soon as the flux stops changing. The voltage is also proportional to the rate of change in flux and not the total change in flux which is often the desired measurement.

With only slight modifications to the integrator, a flux meter can measure periodic AC fields. The integrator output voltage can be processed by a peak detector to find maximum flux or through an RMS converter to find the RMS flux value. The relationships hold true for non-sinusoidal AC fields also.

Keeping drifts or other temperature changes away from the coil lead contacts and resetting the integrator often before every critical measurement will help in minimizing the integrator drift.

III. Components of the Flux Meter

The major component of this flux meter is an integrator. The integrator is very flexible. It performs well in a variety of magnetic applications from a fast pulse to a slow ramp. This flux meter fits well into test and measurement operations from all manual to full automation.

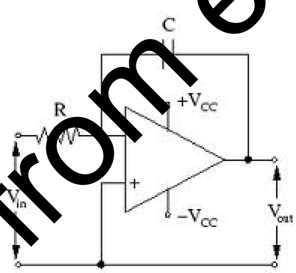

Fig. 3 A Typical Integrator Circuit with No Compensator Resistor

All capacitors exhibit a characteristic that can be described as a tendency to rebound from any fast change. When capacitors are discharged to zero volts momentarily, a small voltage will rise a few seconds later across the capacitor. Likewise, a rapid charge of a capacitor to some voltage will be followed by a slight reduction of that potential occurring over several seconds as in [3]. This characteristic is usually referred to as Dielectric Absorption.

The effect of dielectric absorption in this flux meter is a slight reading change over several seconds after a larger reading change. This occurs predictably during reading changes from 0 to some level and more notably occurs when the reading is reset. A reset from a large, full scale reading will show a "creeping up" of the reading for several seconds after the reset as in [4]. The level of this effect is approximately 0.03% of the reading change.

The effect is most noticeable in the first few seconds and stabilizes after 20-30 seconds. For the most accurate reset of larger measurements an initial reset should be followed by a second reset a few seconds later.

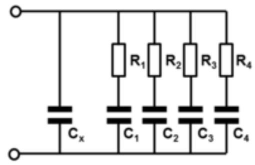

Fig. 4 A Circuit Model for Explaining a Time-Delayed Voltage Build-Up by Parallel RC-Timers

Fast changing, high voltage, or very low voltage signals are integrated most accurately with its integrators.

IV. MATLAB SIMULATION MODEL OF THE FLUX METER

Figure below shows the model of the flux meter created in MATLAB.

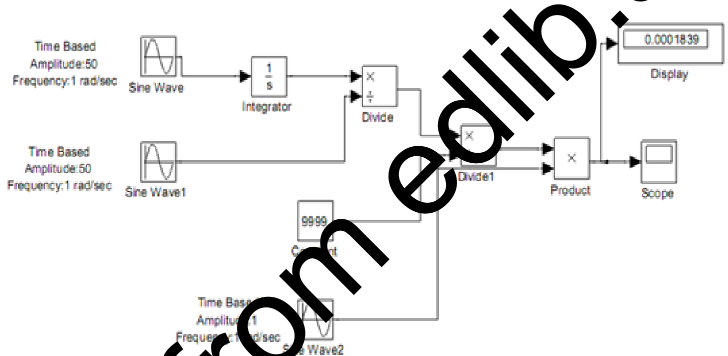

Fig. 5 Simulation Model of the Integrating Flux Meter

Sensing coils are sensitive to AC magnetic fields. Hence this flux meter can measure periodic AC fields over a wide frequency range using simple sensing coils.

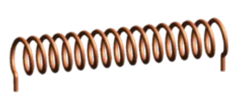

Fig. 6 A Typical Sensing Coil in Flux Meter

Sensitivity is the instantaneous voltage produced for a given rate of change in flux. The coil voltage is directly proportional to the number of turns, as well as the rate of change in flux. Total change in flux can be measured as the flux meter integrates the instantaneous voltage over the measurement interval. Here the coils should be designed so the instantaneous coil voltage does not exceed the rated input voltage of the integrator. Coil resistance is sometimes overlooked because it does not appear in ideal equations for a coil or integrator, but it can limit sensitivity. Wire also has resistance and with more turns resistance can become large. Coil resistance must be accounted for when it is a meaningful percentage of the input resistance of the integrator. Also, dc coil resistance must be added to the integrator input resistance to get an accurate volt second reading.

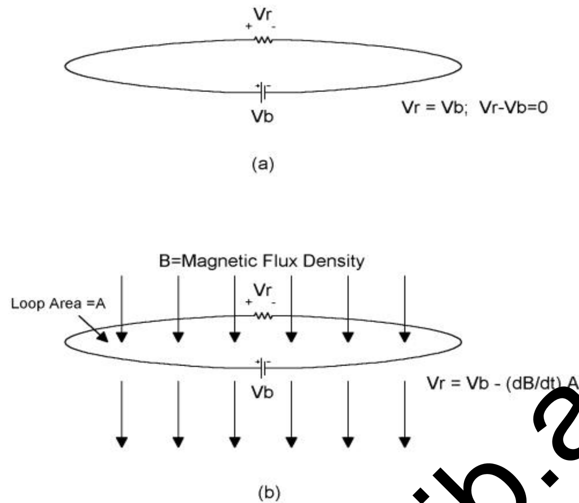

Fig. 7 Effect of Sensing Coil Resistance on Magnetic Flux Density

Coil voltage is related to the number of changing flux lines passing through the center of the coil. The flux measured is a true indication of the number of lines passing through. The angle of the flux lines passing through the coil does not matter but changing coil orientation relative to a magnet often changes the number of flux lines that pass through the coil as in [5]. Orient the coil perpendicular to the flux lines for the most repeatable measurements.

Flux measurement is a true indication of lines of flux passing through a coil as in [6]. Field uniformity does not affect flux measurement, but other magnetic measurements such as flux density assume uniform flux over the coil area.

The flux meter reads the average flux density, while measuring flux density in a non-uniform field. Hence, the coil's length to outer diameter ratio should be optimized to measure flux density at the center of the coil rather than the average flux density.

All loops other than the sensing coil should be eliminated or reduced. Loops in lead wires also witness changing flux as in a coil. Their voltage is an error added or subtracted from the coil voltage. Twisted leads from the coil to the flux meter are needed to reduce loop area and minimize error voltage.

V. POTENTIAL AREAS OF APPLICATION

5.1 Accurate Speed Control At Low Speeds

In speed control, the V-F control facilitates higher proportion of losses and a lower efficiency of the machine. Also the machines exhibit unstable performance at lower speeds as given in [7]. Thus this flux meter can be used in more accurate speed controls at low speeds by the measurement of large ranges of dc and ac flux.

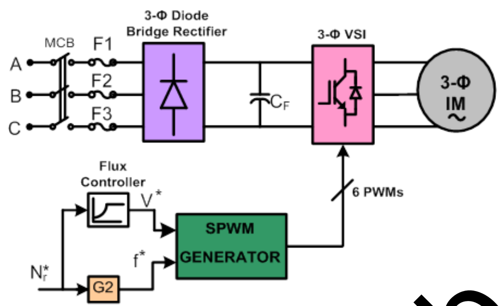

Fig. 8 Block Diagram Schematic of V/F Control of VSI Fed 3-Phase Induction Motor Drive

5.2 Measurement Of Persistent Current

In a super conducting ring, when dc current of large magnitude is induced, the magnetic flux is trapped inside the ring and hence the current persists in the ring for a long time. This current acts to exclude the magnetic field of the magnet.

This current effectively forms an electromagnet that repels the magnet. This flux meter would help in the measurement of this persistent current.

This measurement would incorporate in several applications, like in electric power transmission, transformers, high-performance smart grids, electric motors, power storage devices, magnetic levitation devices, superconducting magnetic refrigeration and fault current limiters, etc., thus leading to higher relative efficiency, smaller size and weight and relatively lower cost.

5.3 Measurement Of Stray Magnetic Field

This meter is useful for measuring stray fields around transformers. It can also be effectively used for measuring stray fields around the poles of a rotating magnet as in [8].

CONCLUSION

The cost part is very much understood from the design itself because with the type of materials used for designing, the cost would be inherently lesser in comparison to its counterparts. Only few of the potential applications are discussed in the paper, a few more could be identified. This could possibly be an area of extension.

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