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EFFICIENT DESIGN OF CAPACITOR DISCHARGE IMPULSE MAGNETIZER SYSTEM FOR 8-POLE MAGNET

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Abstract-This paper describes the efficient design, analysis method and experimental verification of capacitor discharge impulse magnetizer system. A capacitor discharge magnetizer system is used to produce a high current impulse of short duration in this magnetizing fixture. The parasitic resistance and parasitic inductance of the capacitor discharge impulse magnetizer system have been estimated using known air-core test coil. Finite element analysis (using MAXWELL 2-D field simulator) and magnetizing circuit analysis (using SPICE) are also used as part of the design and analysis process of the capacitor discharge impulse magnetizer system. Application study for a magnetizing fixture design is shown. 8-pole magnetizing fixture has been designed and analyzed using finite element analysis. The fixture design for 8-pole magnet are presented along with the experimental results. The experimental results have been achieved using a high-voltage, high-energy capacitor discharge impulse magnetizer and 8-pole iron core fixtures (charging voltage : 2000[V], capacitor bank : 4000[μF]).

I. INTRODUCTION

Various shape magnets such as multipole magnets are used in a variety of applications such as brushless DC motors and for various types of holding magnets. The required pole pattern is produced by placing the magnet in wire-wound fixture and discharging a large capacitor bank through the fixture[1-3].

Modern high-energy magnetic materials such as Sm-Co and Ne-Fe-B require very largy magnetizing fields to achieve full saturation. In some cases the recommended magnetizing field is as high as 40[KOe]. Such a field is readily achievable in a large solenoid, and unidirectional magnetization is easily accomplished. The problem of designing custom fixtures for magnetization fixtures has until recently been a "cut and try" process. It was common to literally blow up one or more fixtures before achieving the desired result.

Finite element CAD package allow the design and analysis of such a fixture. This permit a rapid variation of many parameters without the necessity of fabricating and testing many prototypes. The use of such programs leads to an important reduction in cost development. However, the package must represent the physical behaviour of the fixture. The magnetic field modeling was performed by using a finite element analysis program (MAXWELL 2-D field simulator)[4-6]. Also, the magnetizing circuit analysis for parameter estimation was performed by using SPICE. The desirable results have been achieved by using 8-pole iron core fixtures coupled to a high-voltage magnetizer. This magnetizer system utilizes low-loss oil-filled capacitors (400[μF] × 10) and is capable of a maximum charging voltage of 2000[V].

II. CAPACITOR DISCHARGE IMPULSE MAGNETIZER SYSTEM

Fig.1 shows the capacitor discharge impulse magnetizer system. In Fig.1, a magnet is magnetized by the discharging current of capacitors[1-9]. Since

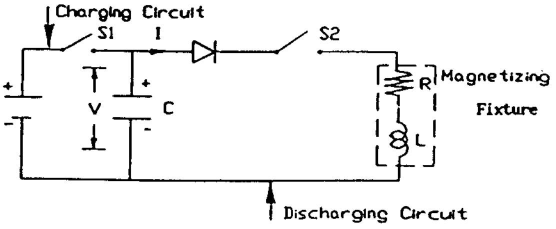


Fig. 1 Capacitor discharge impulse magnetizer system

a typical fixture is essential a fixed configuration of wire loops, its impedance can be modeled as series R-L circuit.

III. EFFICIENT DESIGN METHOD

A. Electrical Parameter Estimation of Impulse Magnetizer System

The initial problem in designing and analyzing a magnetizing fixture is determining the parameters of the magnetizer itself. This impulse magnetizer uses an thyristor to discharge a bank of electrolytic capacitors into a R-L load. On the other hand, the manufacturer was unable to supply the parasitic resistance R_p and parasitic inductance L_p. Therefore, a test fixture was constructed that had a known inductance and resistance. By discharging the capacitor bank into this known test fixture the parameters of the impulse magnetizer could be inferred.

The test fixture is a simple air-core solenoid (mean radius 115[mm] would with 50[turns]) of about 1[mm] diameter wire.(Fig.2) The inductance may be computed from[6]

$$L = \mu_0 N^2 a (\ln (16a / d) - 7/4) \qquad (1)$$

where d<<a and L inductance [H]

$\mu_0 = 4\pi \times 10^{-7}$ [A/m]

N number of turns in toroidal bundle

a mean radius of the coil [m]

d mean diameter of the wire bundle [m]

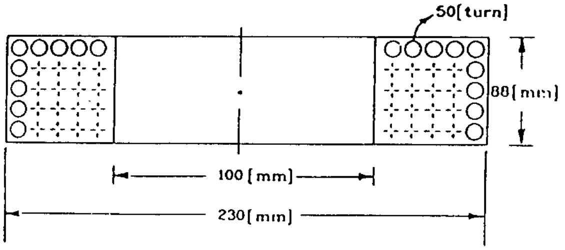


Fig. 2 Cross-section of the air-core test coil

Taking the approximate diameter of the wire bundles as 230[mm], the inductance turns out to be 12.22[mH]. Finite Element Analysis (FEA) using Magnetostat of MAXWELL, produced a result of 12.54[mH].

The measured inductance was 12.72[mH]. The resistance of the air-core test coil was calculated to be 0.292[ohm], and the measured value was 0.314[ohm].

Therefore, parasitic resistance R_p and parasitic inductance L_p were obtained by adjusting the total resistance R_t ($= R + R_p$) and inductance L_p (= the total inductance below saturation) until the computed result closely matched the amplitude and shape of the experimental data. Consequently, a impulse magnetizer has been found to have a parasitic resistance of 0.142[ohm] and a parasitic inductance of 0.075[mH].

B. Parameter Estimation of Magnetizing Fixture

There are two distinct stages in the design cycle of a magnetizing fixture. In the first stage, a fixture configuration is decided upon and the analyst computes a theoretical value of fixture inductance as well as the ratio of megnetic field existing in the fixture per unit of current through it (this ratio is referred to as GPA or Gauss per Ampere)[5]. Based on this ratio one can deteremine the level of current required to produce the desired magnetizing field. FEA is the primary tool used here. In the second stage, a circuit analysis is performed in order to determine the current through the fixture and hence the field that develops across the magnet (using the GPA ratio). The calculation of the fixture inductance is much more involved and usually entails a field theoretic analysis. Since magnetizing fixtures come in a variety of size and shapes, there is usually no simple, closed-form analytic technique that can be used to compute the inductance. Instead, one typically uses finite element analysis. The boundary condition is usually a simple Dirichlet Condition and the FEA program used is MAXWELL 2-D field simulator)[10]. If the computed field is different the prescribed value, the analyst need only linearly rescale the initial current in order to obtain the required magnetizing current.

Once the current level is known all that remains is the inductance estimation. There are various formulas that one can use to estimate inductance. In this study, inductance estimations are generally performed within the calculator mode of the particular finite element package that is being used.

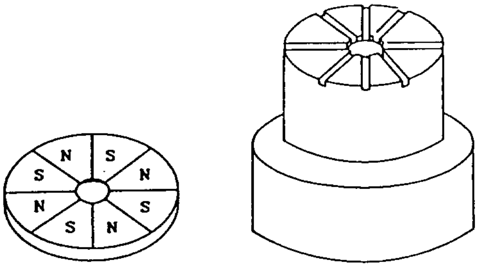
At this point, both the inductance of the fixture and the required current level are known. The question remains, will the impulse magnetizer deliver this current to the fixture given its impedance. One way to determine this is to perform a standard circuit analysis of the impulse magnetizer system. In this paper, a technique for simulating the magnetizing circuits is used computer simulation language SPICE. The resistance of magnetizing fixture is easily estimated from the length, cross-sectional area, and resistivity of the conductor. The fixture resistance R is selected in such a way as to optimize the performance of the impulse magnetizer system. The criteria for optimization are as follows:

1) In order to maximize the current through the fixture, fixture resistance R should be roughly equivalent to the parasitic resistance R_P.
2) The wire should be thin enough to allow for a relatively narrow transition between neighboring poles of opposite polarity (in case of multipole fixtures for high-energy magnet).
3) The temperature of the fixture should remain below 220[℃] during charging[3].

Considering this criteria, the fixture resistance R is selected through magnetizing circuits analysis using SPICE[1-3].

IV. APPLICATION STUDY

Consider the washer-shaped magnet shown in Fig.3(a). Eight north-south alternating magnetic pole are arranged in pie-shaped zones with vertical magnetization over each zone. This type of magnet is typically used in an axial-field brushless dc motor. Fig.3(b) shows an exploded view of the actual test fixture for magnetizing an 8-pole magnet. The material of fixture core is iron and each slots contains one-conductor of 1[mm] diameter wire. Although there is a great deal of symmetry to this fixture, it is truly a 3-D problem to determine the magnetic flux density and inductance. In order to reduce the problem to a more tractable 2-D form, it is necessary to introduce a cylindrical cutting plane at the mean radius of the fixture. This cylinder is then imagined to be unrolled into a 2-D problem with infinite extent into the paper. Fig.4 illustrates this 2-D view of the magnetizing fixture.



(a) 8-pole magnet (b) exploded view of 8-pole fixture

Fig. 3 8-pole magnet and exploded view of 8-pole fixture

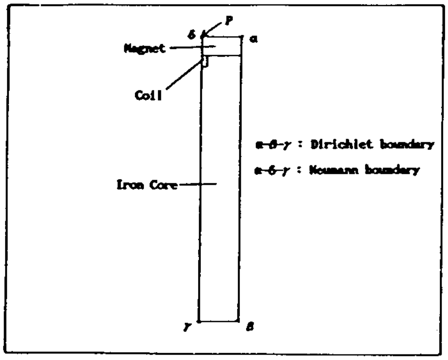
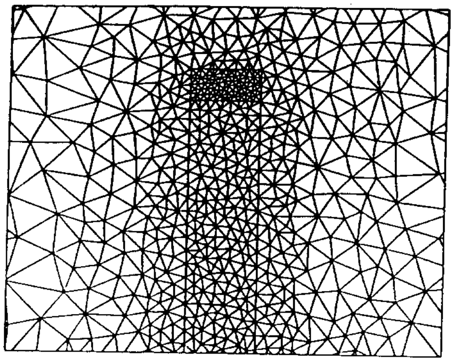


Fig. 4 2-D model of a sector (on half of one pole) of 8-pole fixture

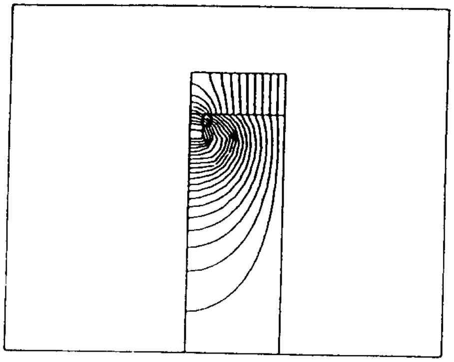
The modeling assumes that the volume extends to ± infinity in the z direction (into the plane of the paper). The resulting 2-D surface consists of one iron region containing 8 slots. The current runs through the slot which contain copper both into and out of page. The magnet to be magnetized is represented by the air gap. The relative permeability of magnetic materials such as ferrite is approximately unity both in the magnetized and unmagnetized states; therefore, the magnet can be represented as an air gap. If one were to model this entire region, the flux lines would surround each of the slots in an elongated elliptical fashion. An identical flux plot would be repeated at every slot. To model the entire region accurately would require a very large number of nodes in the finite element model. The number of nodes can be reduced, however, by taking advantage of the symmetry in the problem. In fact, it is sufficient to model only one section of one pole as shown in Fig.4. The required symmetry is forced by specifying the boundry conditions when running the Magnetostat program as Neumann or Dirichlet.

The actual finite element mesh created by the program MESH is shown in Fig.5(a). It shoud be noted that Fig.5(a) is an enlarged view of the upper side of Fig.4. The magnetic field inside the fixture is found by running MS. The iron is assumed to saturate at 12000[Gauss] and to have a relative permeability of 2000. A plot of the flux lines (prescribed flux density : 2400[Gauss]) is shown in Fig.5(b). Once the field calculation using the design method of above mentioned section III is performed, the key analysis parameters GPA and L are computed. The GPA ratio is simply the 2305[Gauss] divided by the nominal 1100[A] current or 2.095[GPA]. The inductance is calculated using calculator mode of MAXWELL. Therefore, the fixture inductance L is 0.017[mH]. By actual measurement the inductance is found to be 0.02[mH].

Once the inductance and GPA are known, a circuit analysis using SPICE is performed in order to determine the optimum wire gauge. In this case the resulting resistance is 0.16[ohm]. Also, the measured resistance is 0.18[ohm]. Fig.6 shows the flux density on the surface of the magnet in case of rightward checking at the point P (Fig.4).



(a) finite element mesh



(b) magnetic flux density

Fig. 5 Finite-element mesh and magnetic flux density on half of one pole of 8-pole fixture

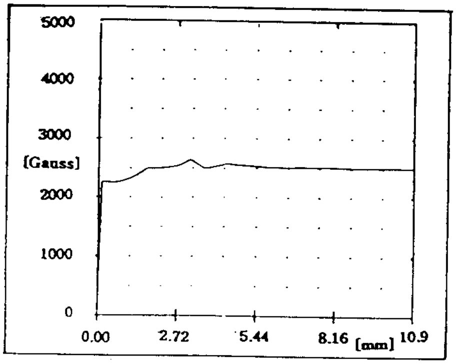


Fig. 6 Flux density along the surface on half of one pole of 8-pole magnet

On the other hand, the current was measured using an shunt (Rating : 400[A]/50[mV], Type : YS-3, Yamaki Electric) in series with the magnetizing fixture. The flux density (= B) was measured using a hall probe of gauss meter (Rating : 10[V]/1000[Gauss], Type : series 9900, F. W. Bell) in the air gap centered on one of the pole. The

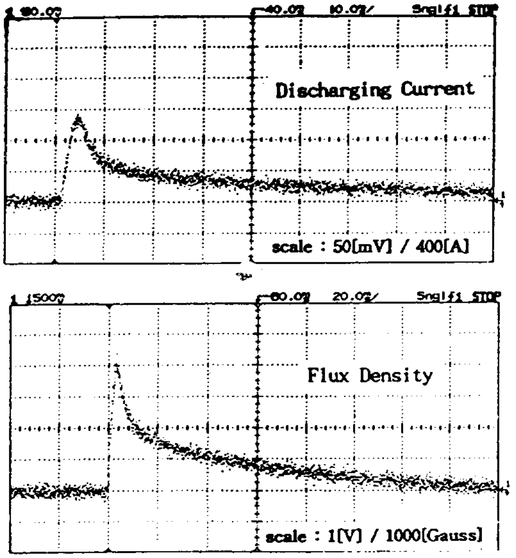


Fig. 7 Measured value from the 8-pole fixture <replotted from storage-type oscilloscope traces (Type : 54601A, Rating : 100[MHz], 4[chan.], HP)>
(capacitor bank : 2800[μF], charging voltage:650[V])

voltage (= V) was measured differentially across the terminals of the impulse magnetizer system using high-voltage probe (Rating : 1000:1, Type : P6015 Probe, Tektronix). The experimental graphs from the magnetizing fixture are shown in Fig.7. The maximum flux density achieved is 2540[Gauss]. This measured maximum value shows very good agreement with the MAXWELL-calculated value. The discrepancy between measurement and calculation may be due to probe nonlinearity or probe placement within the fixture. The calculations are close enough to conclude that the model is reasonably good.

V. CONCLUSION

The efficient method of magnetizing fixture design and analysis have been presented. Application study for a magnetizing fixture design is shown. This fixture has been built and tested. 8-pole magnetizing fixture has been designed and analyzed using Finite Element Analysis (FEA). The magnetic field calculation was performed by using MAXWELL 2-D field simulator. The parasitic inductance and parasitic resistance of a capacitor discharge impulse magnetizer system have been determined by using a known air-core test coil. A 2.88[KJ] impulse magnetizer system has been found to have a parasitic resistance of 0.142[ohm] and a parasitic inductance of 0.075[mH]. Also, in case of 8-pole fixture design, fixture inductance is 0.018[mH] and fixture resistance is 0.17[ohm]. Good agreement between theory and experiment has been achieved.

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