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ORIGINAL ARTICLE

High voltage magnetic pulse generation using capacitor discharge technique

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Abstract A high voltage magnetic pulse is designed by applying an electrical pulse to the coil. Capacitor banks are developed to generate the pulse current. Switching circuit consisting of Double Pole Double Throw (DPDT) switches, thyristor, and triggering circuit is developed and tested. The coil current is measured using a Hall-effect current sensor. The magnetic pulse generated is measured and tabulated in a graph. Simulation using Finite Element Method Magnetics (FEMM) is done to compare the results obtained between experiment and simulation. Results show that increasing the capacitance of the capacitor bank will increase the output voltage. This technology can be applied to areas such as medical equipment, measurement instrument, and military equipment.

1. Introduction

Research on magnetic field generation and application for non-destructive pulse magnetic field shows that the developed system can generate high magnetic field without destroying the magnets [1]. Several methods for generating magnetic field are studied and results show that for nondestructive coil, the peak field depends on the strength of the conductor material [2]. High voltage is required to obtain a high magnetic pulse and capacitor bank is suitable as a pulse source [3]. Fig. 1 shows the schematic diagram of the condenser bank circuit. A high DC voltage is required to charge the 3.3 kV, 9000 μF condenser bank. Ignitron with current capacity of 450 kA is used as the switching device in the condenser circuit.

Multilayer coils are able to generate high magnetic field without destroying the coils [4]. A multi-layer magnet model is shown in Fig. 2. A magnetic pulse is created when a high voltage from a capacitor bank is connected to a coil. A pulse current will flow through the coil resulting in a high magnetic pulse inside the coil. The coil is made of an insulated copper wire and it is covered with galvanized iron. The coil strength can be increased by reinforcing with a uniaxial wrap of fibers [5]. Nonlinear partial differential equations with a field-dependent relative differential permeability are able to solved problems involving intense magnetic field in soft ferromagnetic materials [6]. Pulsed magnet can be designed using computer analysis to reduce the pulsed magnet development time [7]. A capacitor bank with a different value of voltage and capacitance is set up and connected to the coil. This is done to study the magnetic field relationship between voltage and capaci-

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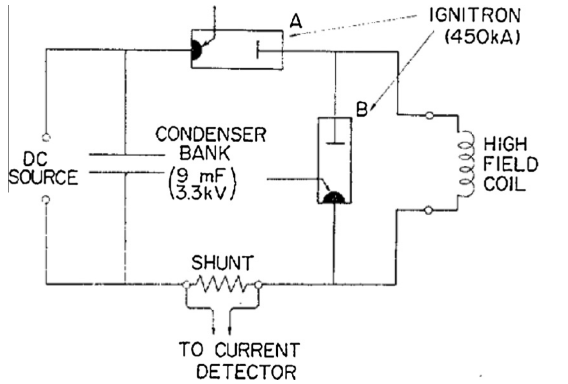

Figure 1 Schematic diagram of condenser bank circuit [3].

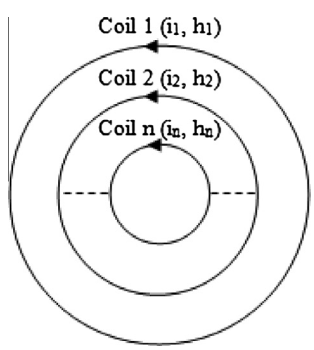

Figure 2 Schematic model of *n*-layer magnet coaxially arranged from coil 1 to *n* [4].

tance. A current sensor and voltage probe are used to measure the magnetic field and voltage across the coil. A search coil is used to measure induce voltage cause by the magnetic field of the coil. The magnetic flux of the coil can be calculated from the induced voltage by integrating the area under the graph of the induced voltage versus time.

2. Mathematical model

2.1. Magnetic field generated by the coil

The magnetic field along the axis of a wire loop is illustrated in Fig. 3 and can be evaluated from the Maxwell's equation as shown in Eq. (1) [8,10]. K is a closed curve around area F, H is the magnetic field strength, I is the current flowing through area F, and D is the electric flux density. The electric flux density is equal to zero when wire is supplied with direct current. Then Eq. (2) is obtained for $D = 0$.

$$\oint_K \vec{H} d\vec{s} = I + \int_F \vec{D} d\vec{f} \tag{1}$$

$$\oint_K \vec{H} d\vec{s} = I \tag{2}$$

Referring to Biot-Savart's Law [9,10], the magnetic field intensity dH produced at a point A, as shown in Fig. 3, by the differential current Idl is proportional to the product Idl and the sine of the angle between the element and the line joining A to the element and is inversely proportional to the square of the distance p between A and the element. Then Eq. (2) can be written as Eq. (3).

$$d\vec{H} = \frac{I}{4\pi} \frac{d\vec{l} \times \vec{p}}{p^3} \tag{3}$$

The vector dl is perpendicular to p and dH lies in the plane of the drawing, so that,

$$dH = \frac{I}{4\pi p^2} dl = \frac{I}{4\pi} \cdot \frac{dl}{R^2 + z^2} \tag{4}$$

dH can be resolved into a radial dH_r and axial dH_z component. The dH_z components have the same direction for all conductor elements dl and the quantities are added; the dH_r components cancel one another out, in pairs. Therefore,

$$H_r(z) = 0 \tag{5}$$

and

$$H(z) = H_z(z) = \frac{I}{2} \cdot \frac{R^2}{(R^2 + z^2)^{3/2}} \tag{6}$$

along the axis of the wire loop, while the magnetic flux density,

$$B(z) = \frac{\mu_0 I}{2} \cdot \frac{R^2}{(R^2 + z^2)^{3/2}} \tag{7}$$

where $\mu_0 = 1.2566 \times 10^{-6}$ H/m is the permeability of free space. If there is a small number of identical loop close together, the magnetic flux density is obtained by multiplying by the number of turns N. The magnetic flux density of a

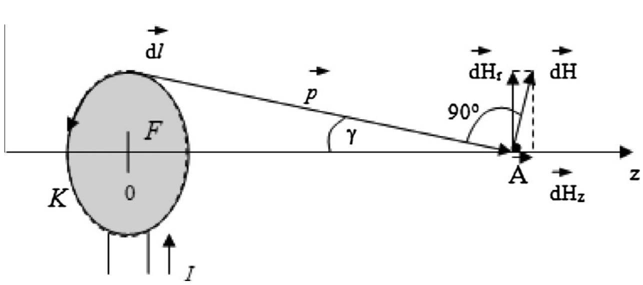

Figure 3 Magnetic flux density from wire loop [10].

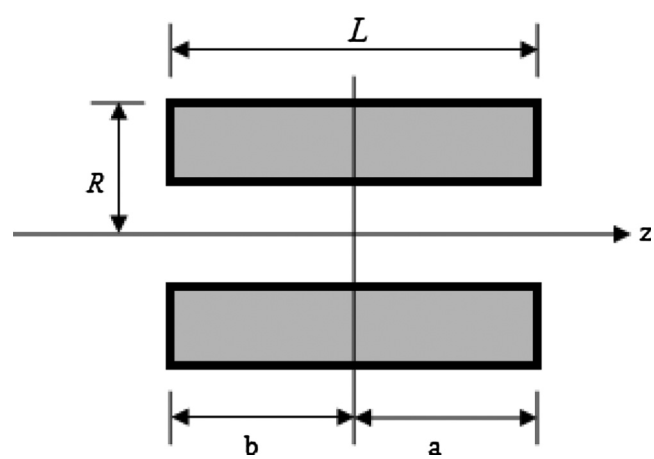

Figure 4 Cross-sectional view of coil.