http://ansinet.com/itj

ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet

Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 11 (4): 446-450, 2012
ISSN 1812-5638 / DOI: 10.3923/itj.2012.446.450

Theoretical and Experimental Research on MFCG

[1,2]Zhu Yichao, [2]Chen Yu, [2]Luo Genxin, [2]Li Hao and [2]Qiu Shuang
[1]Engineering Institute of Engineering Corps, PLA University of Science and Technology, Nanjing Jiangsu, 210007, China
[2]The First Engineers Scientific Research Institute, Wuxi Jiangsu, 214007, China

Abstract: The operating process of Magnetic Field Compression Generator (MFCG) is described and its design principle is analyzed theoretically. The simulation method is studied and a software program is written according to the MFCG operation. The simulation results comply with the theory. Moreover, MFCG equipment is designed and the experiment is carried out to test its performance. The result shows that the electric current is amplified nearly 48 times.

Key words: Magnetic field compression generator, magnetic flux, energy magnification factor, simulation

OPERATION PRINCIPLE

MFCG is a compact device which transforms chemical energy into electromagnetic energy and it provides energy for electron accelerator, electromagnetic-pulse weapon, etc., its principle is based on magnetic field freezing effect that the magnetic flux inside random closed circuit in moving conductor is constant. The helical MFCG is composed of solenoid, amature and other components (Graham, 1999). Its structure is shown in Fig. 1.

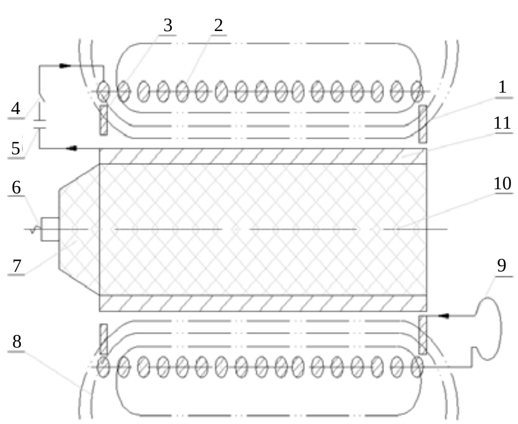

Fig. 1: Sketch of helical MFCG. 1: Insulating support; 2: Solenoid; 3: Wrecking switch; 4: Discharging switch; 5: Storing capacitor; 6: Detonator; 7: Generator of plane wave; 8: Magnetic line of force; 9: Load; 10: Main dynamite and 11: Metal armature

It is shown that the discharging circuit is composed of capacity, discharging switch, solenoid, load and detonator. Firstly, the discharging switch is closed and then the capacity discharges around the circuit. The electric current in the circuit loop produces magnetic field. When the current comes to maximum, the detonator is ignited and leads the generator of plane wave to ignite the main dynamite. Then, the dynamite drives the metal armature to expand and contact the solenoid. The circuit loop captures magnetic flux. According to the magnetic flux conversation law, the current is amplified thousands times. Figure 2 shows the chart that how the magnetic field inside the coil is compressed. In this chart, the magnetic field is

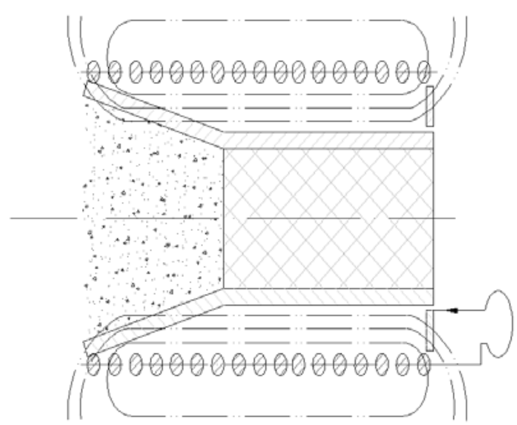

Fig. 2: The chart of helical MFCG's operation

Corresponding Author: Zhu Yichao, Engineering Institute of Engineering Corps, PLA University of Science and Technology, 210007, China

compressed by the armature from left to right which is driven by the dynamite. So the magnetic energy is enhanced.

EQUIVALENT CIRCUIT AND DESIGN PRINCIPLE

The MFCG's performance is three-dimensional and more complicated. It is difficult to solve the problem accurately. So the equivalent circuit is adapted to analyze the MFCG's performance and the circuit diagram of helical MFCG is shown in Fig. 3. Where, C represents storing electric capacity; K1 represents discharging switch; K2 represents wrecking switch; Lf and Rf represents the inductance and resistance of the load; Le (t) and Re (t) represent the inductance and resistance of the generator in the t time and I (t) represents the electric current in the loop.

The circuit equation of MFCG is displayed as follows:

$$\frac{d}{dt}[L(t) \bullet I(t)] + (R_e(t) + R_f) \bullet I(t) = 0 \tag{1}$$

where, L (t) represents the total inductance:

$$L\,(t) = L_e\,(t) + L_f \tag{2}$$

The Eq. 1 can be inferred that:

$$I(t) = \frac{L_0 \bullet I_0}{L(t)} e^{-\int_0^t \frac{R_e(\tau)+R_f}{L(\tau)} d\tau} \tag{3}$$

L_0 and I_0 represent the initial state and $L_0 = L_e\,(0) + Lf$; $I_0 = I\,(0)$.

The magnetic flux factor Φ (t) is defined as the ratio of magnetic field at the *t* time to the initial magnetic flux to indicate the loss quantity of magnetic flux:

$$\phi(t) = \frac{L(t) \bullet I(t)}{L_0 I_0} = e^{-\int_0^t \frac{R_e(\tau)+R_f}{L(\tau)} d\tau} \tag{4}$$

The inductance compressed coefficient ψ (t) is means the ratio of the initial inductance to the inductance at the t time:

$$\psi(t) = \frac{L_0}{L(t)} \tag{5}$$

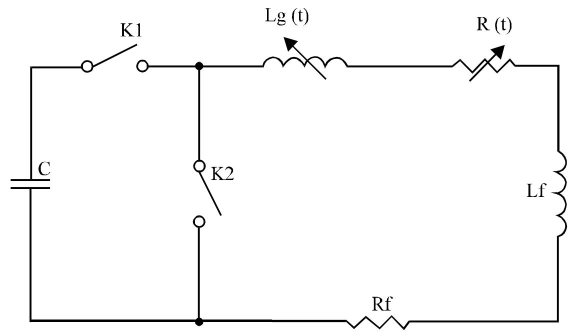

Fig. 3: Equivalent circuit diagram of helical MFCG

The magnification of electric current λ (t) is defined as:

$$\lambda\,(t) = \frac{I(t)}{I_0} \tag{6}$$

The Eq. 3 is converted into:

$$I\,(t) = I_0 \bullet \phi\,(t) \bullet \psi\,(t) = I_0 \bullet \lambda\,(t) \tag{7}$$

Then:

$$\lambda\,(t) = \phi\,(t) \bullet \psi\,(t) \tag{8}$$

So, it is concluded that the magnetic flux coefficient is lager, the magnetic flux losses is less, the inductance compressed coefficient grows faster and the magnification of current goes higher.

The variable E (t) is defined as the energy output of MFCG at the t time:

$$E\,(t) = \frac{1}{2} L(t) \bullet I^2(t) \tag{9}$$

Then the initial energy E_0 is:

$$E_0 = \frac{1}{2} L_0 \bullet I^2{}_0 \tag{10}$$

It can be inferred that:

$$E\,(t) = \psi\,(t) \bullet e^{-2\int_0^t \frac{R_e(\tau)+Rf}{L(\tau)} d\tau} \bullet E_0 \tag{11}$$

The current in the loop is monotone increasing, namely that is dI (t)/dt>0. It can be derive that:

$$-\frac{dL_e(t)}{dt} > R_e(t) + R_f \tag{12}$$

Moreover, the energy output is also monotone increasing, namely that is dE (t)/dt>0. It can be concluded that:

$$-\frac{dL_e(t)}{dt} > 2[R_e(t) + R_f] \qquad (13)$$

It can be seen that Eq. 13 is the criteria that the current and energy have gain in the compressing process of MFCG.

The energy magnification factor is defined that (Fowler, 1989):

$$\lambda_E = \frac{E(t)}{E_0} = \frac{L(t)\bullet I^2(t)}{L_0\bullet I_0^2} = \psi(t)\bullet\phi^2(t) \qquad (14)$$

It is concluded that the energy magnification is directly proportional to the inductance compressed coefficient and has square relation with the magnetic flux factor.

In the process of MFCG performance, the coil contacts the armature continuously. The increment of axial magnetic energy is equal to the kinetic energy of armature's movement. The kinetic energy of the armature being moved a unit length is:

$$W_m = \frac{1}{2}\bullet\frac{d}{dx}[(L_e(x) + L_f)\bullet I(x)^2] \qquad (15)$$

where, L_e (x) is the MFCG's inductance when the armature is moved to the location(x) and it changes as the armature contacting with the coil.

Assuming that there is no magnetic flux loss, the magnetic flux is constant at any time:

$$(L_e(x) + L_f)\bullet I(x) = (L_{e0} + L_f)\bullet I_0 \qquad (16)$$

Then:

$$I(x) = \frac{(L_{e0} + L_f)\bullet I_0}{(L_e(x) + L_f)} \qquad (17)$$

It can be inferred by derivation:

$$\frac{d(I(x))}{dx} = -\frac{d((L_e(x)))}{dx}\bullet\frac{I(x)}{(L_e(x) + L_f)} \qquad (18)$$

It can be inferred by putting the Eq. 17 and 18 into Eq. 15:

$$L_e(x) + L_f = \frac{(L_{e0} + L_f)\bullet W_0}{W_m\bullet x + W_0} \qquad (19)$$

where, W_0 represents the initial energy of MFCG:

$$W_0 = \frac{1}{2}\bullet(L_{e0} + L_f)\bullet I_0^2 \qquad (20)$$

As the armature contacting the coil continuously, the inductance of MFCG becomes less, the current grows more largely and the magnetic flux intensity grows more strongly. This is the principle that the helical MFCG compresses magnetic flux.

The solenoid's pitch has something to do with the axial distance which is represented by D (x):

$$L_e(x) + L_f = \int_x^1 \mu_0\bullet S\bullet[\frac{L}{D(x)}]^2 dx + L_f = \frac{W_0\bullet(L_{e0} + L_f)}{W_0 + W_m\bullet x} \qquad (21)$$

where, L represents the solenoid's length, ì$_0$ represents the magnetic permeability of free space:

$$D(x) \approx \left[\frac{\mu_0 S W_0}{(L_{e0} + L_f)W_m}\right]^{\frac{1}{2}}\bullet\left[1 + \frac{W_{mx}\bullet x}{W_0}\right] \qquad (22)$$

It can be seen that, as the armature contacts the coil continuously, the pitch should be increased continuously. Moreover, the diameter of coil should be thicker, to ensure the leading wire conductive ability. As a result, the pitch and diameter of the helical coil is designed partitioned.

SIMULATION AND EXPERIMENT

According to the above theory and numerical method, a relative program is written to calculate the inductance, current and energy in operation (Fowler, 1989). Then, the parameters of MFCG are conformed by comparison and its simulation result is displayed in Fig. 4.

Based on the simulation results, the MFCG is designed and developed. The experiment is carried out and the layout of experimental equipments is shown in Fig. 5. The rogowski coil is adapted to measure the electric current in the discharging loop. The control and measuring instruments are put in the shield room.

Figure 6 shows the waveform measured from the oscillograph. The first channel is the current discharged by electric capacity and the second channel is the current in the solenoid coil. The current magnification time of MFCG is 48.3 by the means of conversion.

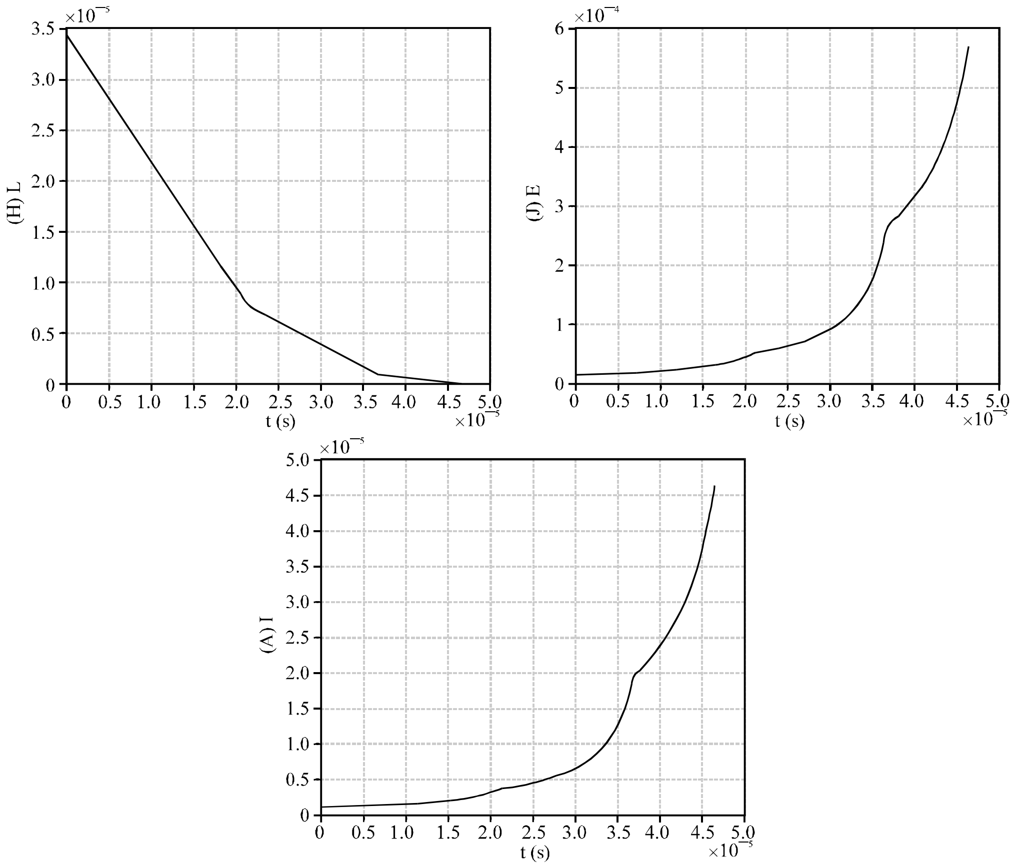

Fig. 4: Simulation results of inductance, current and energy

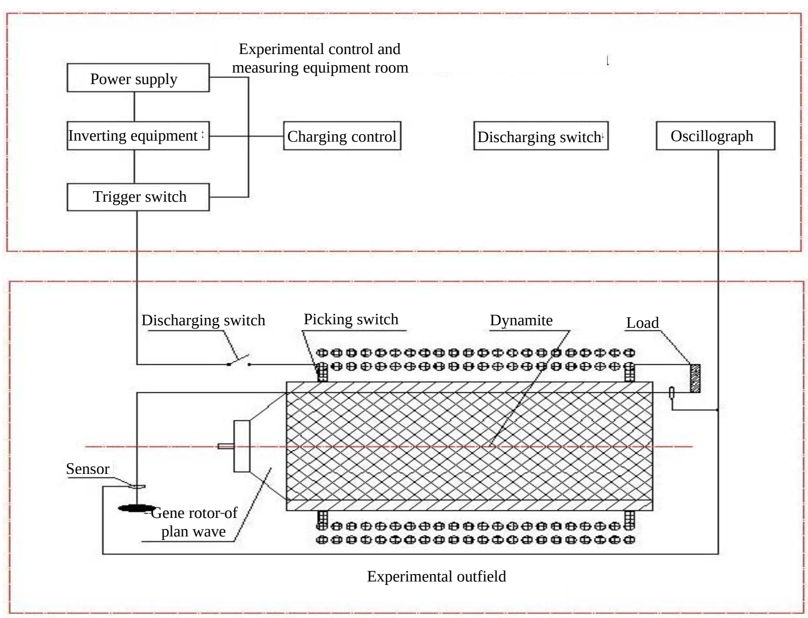

Fig. 5: The layout of experimental equipments

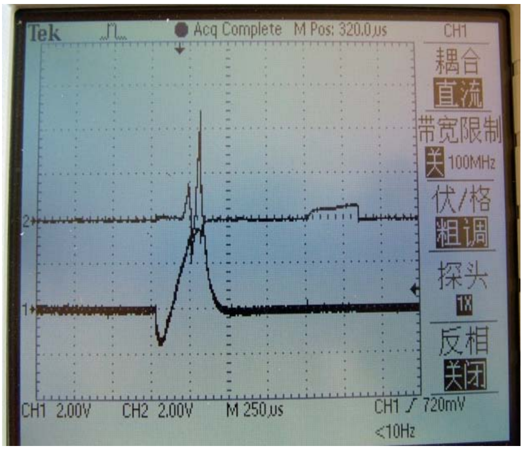

Fig. 6: Measuring result

CONCLUSION

Based on the theoretical analysis of the MFCG's operation, a simulation program is designed. Combing with the designing demands, the simulation results are accomplished and compared with each other. The best parameters are confirmed. At last, MFCG equipment is developed and its experiment is carried out.

REFERENCES

Fowler, C.M., 1989. Magnetic flux compression. Proceedings of the American Physical Society Topical Conference on Shock Compression of Condensed Matter, August 14-17, 1989, Albuquerque, NM., USA.

Graham, R.A., 1999. Magneto-Cumulative Generators. Springer-Verlag, New York, USA.