*32nd EPS Conference on Plasma Phys. Tarragona, 27 June - 1 July 2005 ECA Vol.**29C**, D-5.004 (2005)*

2D MHD description for a helical magnetic flux compression generator[1]

Dong zhiwei Wang yuzhi Wang guirong Yang xianjun Zhaoqiang

Institute of Applied Physics and Computational Mathematics

P.O.Box 8009, Beijing 100088, P.R.China

Helical magnetic flux compression generators (HMFCG)[1] driven by high explosive are widely used in a variety of high-energy and high current application, especially in a single shot, at remote location applications. The general principles of HMFCG are reasonably well documented [2]. Up to now most researches on HMFCG are focused on how to enhance the energy exchanging efficiency and suitable to the special application requirements., but there are little concerns on its basic physical process and loss mechanism. Meanwhile as the single shot, self-destroyed device, HMFCG exists a lot of measurement and diagnosis difficulties. Also most previous research works are performed at national laboratories, quite a lot valuable research results are still classified. MFCG-II is a 2D MHD code constructed to study the basic physical process and characteristics of a helical magnetic flux compression generator, includes the Joule heating, Lorentz forces, a circuit equation to an external load, a model for explosive burn and necessary state equations for some materials. Compared with its old version, MFCG-I [3], the calculation efficiency and precision are largely enhanced. In this paper, the basic physical model and the main equations are brief introduced in section 1. In section 2, the simple wound HMFCG device developed in TTU, USA, is described briefly, while in section 3 MFCG-II is used to simulate the series of experimental results of the simple wound HMFCG device in TTU, USA. The effect of the nonlinear impedance loss on HMFCG performance due to the difference of the seed current is also studied. The agreement between experimental and numerical results is quite satisfactory. Finally conclusions are presented.

1 MHD description for HMFCG

In a HMFCG, chemical explosives are used to compress the initial magnetic flux

[1] Work supported partially by National Natural Science Foundation(Contract 10475012)

(provided usually by capacitor bank, called seed source) by driving a conducting surface (called armature) which contains the flux. Works by the moving conductors against the contained magnetic fields results in an increase in the electromagnetic energy. The additional energy comes from the chemical energy originally stored in the explosives.

The basic dynamic equations for describing MFCG process are as follows.

$$\frac{\partial N}{\partial t}+N\left(\frac{\partial u}{\partial r}+\frac{u}{r}+\frac{\partial v}{\partial z}\right)=0 \tag{1}$$

$$N\frac{\partial u}{\partial t}=-\frac{\partial(p+q)}{\partial z}-B\frac{\partial p_r}{\partial z}+A_1\frac{B_r}{4Pi}\frac{\partial B_z}{\partial r} \tag{2}$$

$$N\frac{\partial v}{\partial t}=-\frac{\partial rp}{r\partial r}+\frac{p}{r}-\frac{\partial q}{\partial r}-\frac{\partial p_z}{\partial z}+A_2\frac{B_z}{4Pi}\frac{\partial B_r}{\partial z} \tag{3}$$

$$N\frac{\partial e}{\partial t}=-\frac{p}{r}\cdot\frac{\partial rv}{\partial r}-\frac{\partial rqv}{r\partial r}+v\frac{\partial q}{\partial r}-p\frac{\partial u}{\partial z}-\frac{\partial qu}{\partial z}+u\frac{\partial q}{\partial z}+A_3\frac{10^7}{NQ_a}\bar{J}_c^2 \tag{4}$$

$$P=f(N,T) \tag{5}$$

Where the definition of the parameters can be found in the reference [3], most of them are routine. Among them N is the density, $P_r=B_r^2/8Pi$, $P_z=B_z^2/8Pi$, $\bar{J}_c=I_{aj}/\Delta z(r_{out}-r_{in})$, and r_{out}, r_{in} are the outer and inner radii of the armature, respectively. $-B\cdot\partial p_r/\partial z+A_1\cdot B_r/4Pi\cdot\partial B_z/\partial r$ and $-\partial p_z/\partial z+A_2\cdot B_z/4Pi\cdot\partial B_r/\partial z$ are the Lorentz force in *r* and *z* directions. $10^7\cdot A_3/NQ_a\cdot\bar{J}_c^2$ is the Joule heat contribution, and B, A_1, A_2, A_3 are some switching constant[3]. I_{aj} is the introduced current in the outer surface of the armature, and the magnetic pressure on the armature surface is

$$P(r_{out},z_j)=\frac{1}{8Pi}(B_r^2+B_z^2) \tag{6}$$

For a two dimensional model, the magnetic diffusion equations are

$$\frac{\partial F}{\partial t}=v\left[\frac{\partial^2 F}{\partial r^2}-\frac{\partial F}{r\partial r}+\frac{\partial^2 F}{\partial z^2}\right]\quad ,B_r=-\frac{\partial F}{r\partial z}\,,B_Z=\frac{1}{r}\frac{\partial F}{\partial r},$$

$$\frac{\partial^2 F}{\partial r^2}-\frac{\partial F}{r\partial r}+\frac{\partial^2 F}{\partial z^2}=-0.4Pi\,r\,j;\quad (j=j_c) \tag{7}$$

where $F = A_c r$ is the azimuthal component of the magnetic stream function.

Given the detonator is ignited at t_0, the armature begins to expand and the MFCG circuit is closed($t \geq t_0$), its equivalent circuit equations are normal[3], For a multi-section coil stator, the general magnetic flux losses are

$$R_c = \sum_{j=M+1}^{J_P} \left(\frac{N_j l_j L_j}{K_j P_j \cdot \Delta R} \right) + \frac{N_M l_M N_M}{K_M P_M \cdot \Delta R} \cdot \frac{m'_M}{m_M} \tag{8}$$

where J_P is the initial total section number, L_j is the pitch number of the j section, M is already collided pitch number, m_M is the total cell number while m'_M the un-collided cell number within the M section.

2 Simulation Results for the Single pitch HMFCG

In order to study the basic physical process and compare with the experimental results, we chose to simulate the single pitch HMFCG developed by TTU,using its all parameters. This is a very conservative HMFCG that should perform extremely reliable, i.e. the output current amplitude should be highly reproducible.

Using exactly the measured parameters without any modulated parameter, we simulated the experiment with the seed current of 8 kA, the simulation results of current amplification and inductance collapse are shown in Fig 1, which show very good agreement with the measured curves.

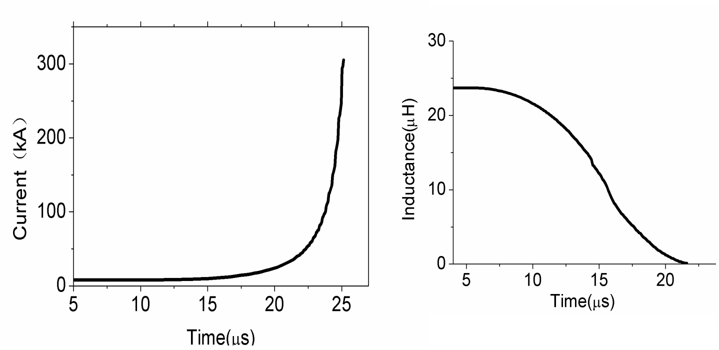

Fig 1 Generator current waveform and inductance collapse simulated by MFCGII

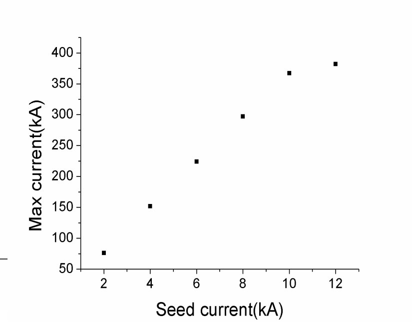

Fig 2 Dependence of the output current on seed current.

For the experiment with seed current of 12kA, the final simulated current is 396kA, about 4% higher than the measured one, which should be attributed to the soften armature during the last part of the process, while this characteristic is not included in the simulation yet. In order to study the non linear relationship between the electrical conductivity and the Joule deposit heat, simulations are made for different seed currents, as shown in Fig 3. The simulation results indicated that with the seed current over 8kA, TTU-1 HMFCG device works in the non linear region, that means the output current is not increased linear with the seed current.

3 Conclusions

A new 2D MHD code for HMFCG has been developed, some comparison with experiments are made, and the agreement between experimental and numerical results is found quite satisfactory. The code has also been used to study the effects of the nonlinear impedance loss on MFCG performance due to the difference of the seed current. The impact of this research on the present understanding of magnetic flux losses in helical MFCG is also briefly discussed.

References

[1] C.M.Fowler, R.S.Caird,and W.B.Garn,“ An introduction to explosive magnetic flux compression generators”, Los Alamos National Laboratory, Report LA-5890, 1975 B. M.

[2] Novac, I. R. Smith, H.R.Stewardson, P.Senior, et al“ Design, construction and testing of explosive-driven helical generators,” *J. Phys. D., Appl. Phys.*, vol. 28, pp. 807–823, 1995.

[3] Wang yu-zhi,Wang Gui-rong et al,“ Contrast and analysis of the results computed by 2-D cylindrical coordinate system MHD codes MFCGII and MFCGI”,High power laser and particle beams, 2003, 15(9), 899-904] (in Chinese).

[4] A. Neuber, J. Dickens, J.B.Coenette, et al, “ Electrical behavior of a simple helical flux compression generator for code benchmarking , ” *IEEE Trans. Plasma Sci.*, vol. 29, No.4, pp. 573–581, 2001