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Ernst-Mach-Institut

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**Proceeding of the 15th IEEE International Pulsed Power
Conference**

13-17 June 2005, Monterey, CA, USA

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A MAGNETIC FLUX COMPRESSION GENERATOR WITH HIGH ENERGY DENSITY

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Abstract

RWM and FHG-EMI started a joint effort to build and test a high energy density Magnetic Flux Compression Generator (MFCG, FCG or MCG) for high power microwave applications.

Based on the helical magnetocumulative generator-type, Mini-FCGs with a total volume of about 960 ccm and an effective explosive charge of 0.04 kg were manufactured and experimentally tested through 1998 to 2003.

The generators produced output currents greater 265 kA with a current gain of 60 and a maximum energy multiplication of approximately 17.

The output currents were measured in two different ways using the common Rogowski coil and a fiber optical coil sensitive to the Faraday Effect of optical polarization.

Further developments and tests using integrated dynamic transformers have the goal to increase the performance and output voltage and identify the limits of the applied technology.

The paper gives an overview on the Mini-FCGs used and its test results obtained so far.

I. INTRODUCTION

Magnetic Flux Compression generators have been investigated since 1952. The first intention was to generate super-high magnetic fields of 1000 and more Tesla for atomic fusion. Because of the general principle of MCGs it is possible to convert chemical energy stored in high explosives into magnetic and/or electrical energy. Two types of MCGs have been designed, the first to generate electrical energy the second to generate super-high magnetic fields, RWM and EMI are especially interested in the potentiality to excite very high voltages for UWB application.

II. FIRST TYPE OF MAGNETIC FLUX COMPRESSION GENERATOR

In the beginning we started to build MCGs with a simple type of helical coil to get basic information on the generator, for example, opening angles of the liner, speed of detonation, manufacturing of winding etc.

Based on the classification made by B.M. Novac and I.R. Smith [1] it would fit into the Mini-Class regarding its parameter values.

A. Parameters

Length [mm]:	350	
Diameter [mm]	88	stator
	150	over all
Total Mass [kg]	10	
Explosive Mass [kg]	0.5	
Current [MA]	0.265	
Energy [MJ]	0.02	
Compression time [μ s]	19	

B. Layout

During the Layout phase the MCG was designed according to the solution of the equations:

$$L(t) \cdot \frac{dI(t)}{dt} + I(t) \cdot \frac{dL(t)}{dt} + R(t, I, \frac{di}{dt}) \cdot I(t) = 0 \quad (1)$$

And

$$I \sim \frac{1}{L}, \quad W = \frac{LI^2}{2} = W_o \frac{L_o}{L} \quad (2)$$

To start with a more simplified equation the inductance can be described as decreasing linearly with a remaining inductance L_{end} .

$$L(t) = \frac{L_0(1-t)}{t_{end}} + L_{end} \quad (3)$$

By variation of the parameters inductance, remaining inductance, resistance and different rates of compression

in a simulation the interdependencies and the influence on the current amplitude were analyzed.

On this basis the mechanical process inside the MCG was examined.

First a simulation of the gradient of the armature was implemented with Autodyn 3D. In this simulation the detonation was assumed to be planar, the armature material was copper (OFHC) and Composition B was used as explosive with a speed of detonation of 7980 m/s.

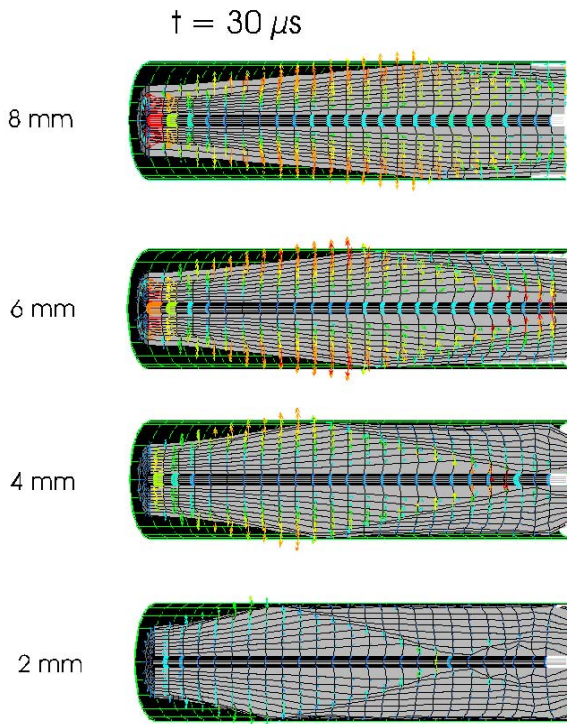


Figure 1. Simulation result of Autodyn 3D. Evaluation of expansion in interdependence of armature thickness.

The Simulation gave a good overview on the cone angles of the liner in relation to the wall thickness.

Table 1. Cone angles.

Wall thickness [mm]	Cone angle [deg]
2	14,7
4	9,95
6	7,1
8	5,4

It is not possible in this simulation to determine the exact behavior of the copper, such as, for example, cracks in relation to armature expansion. Therefore a first test setup was constructed to detonate different armatures to verify the obtained values. Furthermore we determined the armatures limit values of expansion without cracks.

C. Construction

The stator was kept simple to reduce costs and to get a general overview of the influences of the different parameters. The inductance consists of an inlet, a linear coil and a metallic outlet. The whole system is enclosed by a glass-fiber reinforced plastic winding

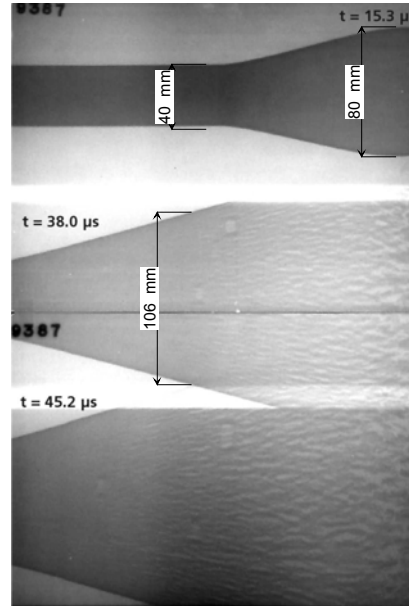


Figure 2. Armature X-Ray (Copper 40x2x300 mm, Composition B 523 g).



Figure3. MCG.

D. Measurement

To measure the output-current, commonly used Rogowski coils were embedded; additionally a less frequently used fiber-optic coil using the Faraday Effect of optical polarization was also assembled.

Both types were calibrated with a stator short circuit with several kilo amperes.

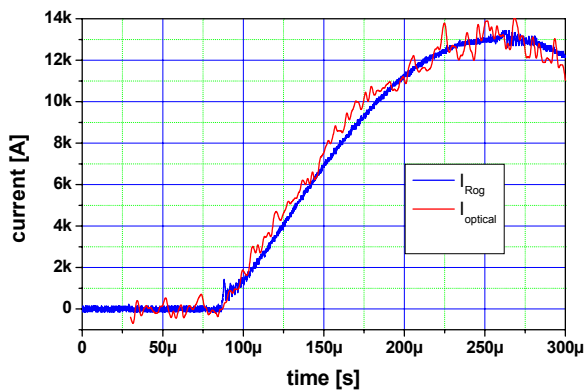


Figure 4. Comparison of current, measured with Rogowski coil and optical method.

With calibrated coils five tests were made with good results. The current achieved always more than 200 kA and the deviation was smaller than 10 %.

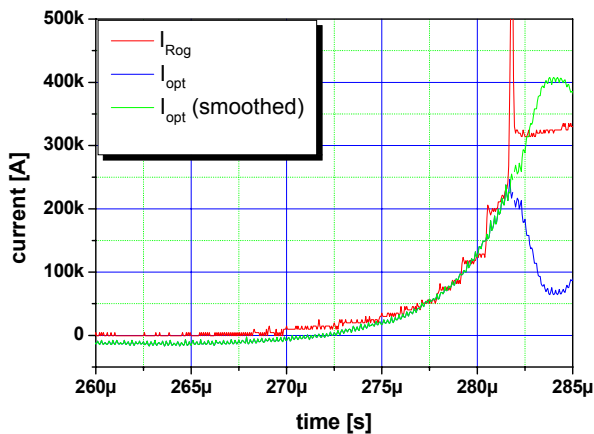


Figure 5. MCG current.

III. SECOND TYPE OF MAGNETIC FLUX COMPRESSION GENERATOR

In the next step a conical type of MCG was designed to increase the current multiplication and to examine another type of MCG [2].

The approach of design was similar to that described for the first MCG. With the design showed in Figure 6 the results of a total of five tests were not satisfying. Many problems occurred such as, for example, 2π -clocking, armature cracks and voltage breakdown.

After these tests the decision was made not to invest too much time and money in that type of MCG and to improve the design of the former used MCG and to reduce the amount of high explosive used.

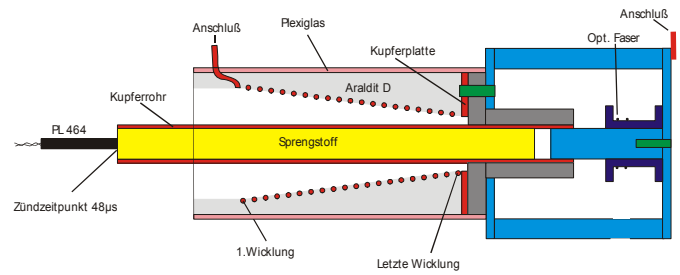


Figure 6. Layout of Conical MCG.

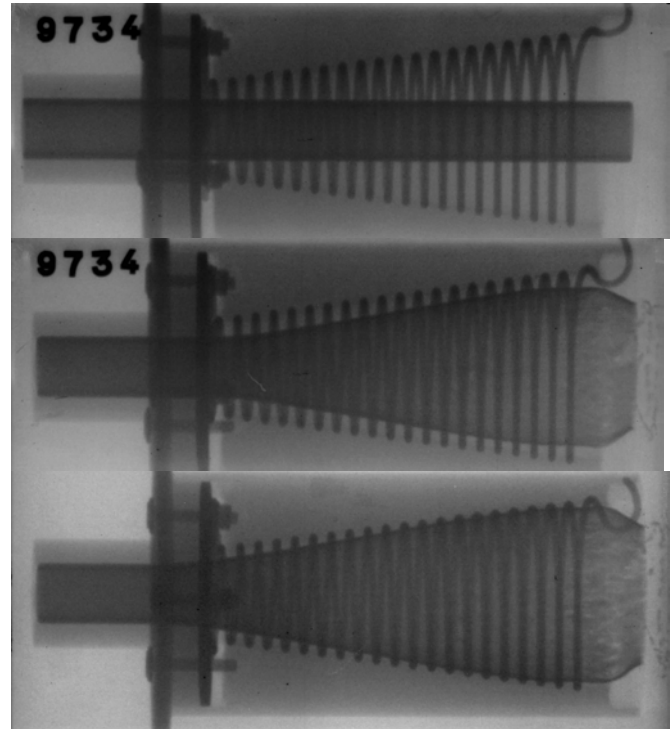


Figure 7. X-Ray of MCG at $t=0\mu s$, $15.4\mu s$ and $18.1\mu s$.

IV. THIRD TYPE OF MAGNETIC FLUX COMPRESSION GENERATOR

In the third step of the MCG development a more sophisticated stator design was chosen. It consists of ten coil sections with different turns and different wire thickness.

A. Parameters

Length [mm]:	370	
Diameter [mm]	30	stator
	140	over all
Total Mass [kg]	5.7	
Explosive Mass [g]	45-49	
Current [MA]	0.267	
Energy [MJ]	0.02	
Compression time [μs]	44	

The inductivity of the stator coil was chosen to minimize the generated voltage to obey the constant voltage rule [2].

During the design and test-phase seven experiments (No. 10-16) for parameter verification and manufacturing improvement were performed.

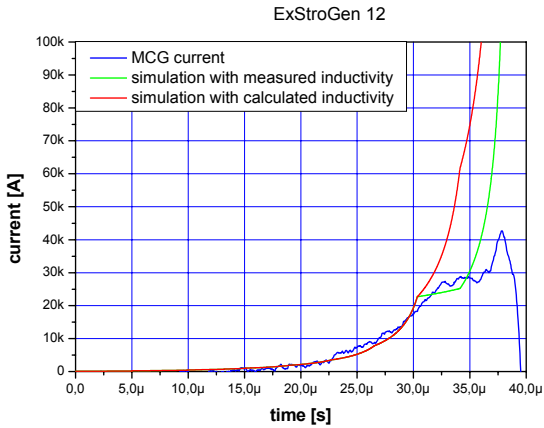


Figure 8. Comparison of Simulation and Test Result.

With this final design an adjustment phase was hooked up to optimize current gain so that at the end of this series the above mentioned parameters were obtained. (No. 17-25). With this optimized design a new test series (No. 26-29) was started to verify this system.

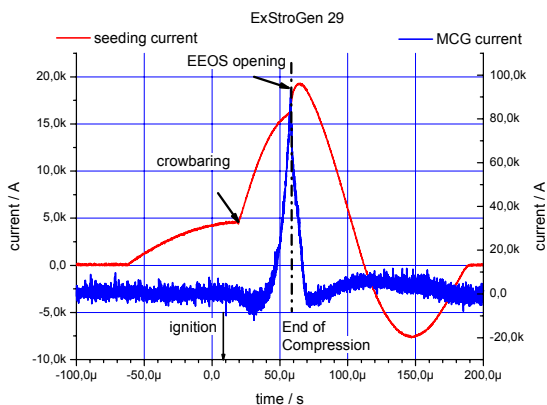


Figure 9. MCG current.

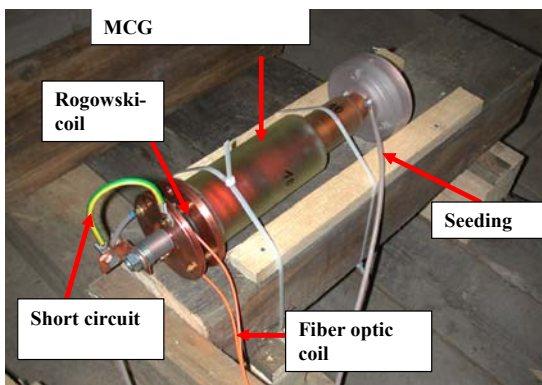


Figure 10. MCG Test Setup.



Figure 11. MCG Test Setup.

V. SUMMARY

During 1998 up to 2003 nearly thirty tests with three different types of MCGs were performed with the aim of minimizing the lethality by reducing size and therefore the amount of high explosive. The test results obtained so far show the potential of this technology, it was possible to generate the same current with one tenth of the mass of high explosive by design adjustment with nearly the same size and weight. The further development is aimed at integrating dynamic transformers, Flux Traps and cascades to match high impedance loads.

VI. REFERENCES

- [1] Novac, B. and Smith, I.R., "Classification of Helical Flux-Compression Generators", Proceedings of the VIIIth International Conference on Megagauss Magnetic Field Generation and Related Topics, Tallahassee, October 1998
- [2] Novac, B.M., Smith, I.R., Stewardson, H.R., Senior, P., Vadher, V.V. and Enache, M.C., "Design, Construction and Testing of Explosive-Driven Helical Generators", J Physics D, Applied Physics, 28, April 1995, pp 807-823
- [3] Boriskin, A.S.; Brodsky, A.Ya., Vinogradov, A.B., Dimant, Ye.M., "Fast Conical Helical MCG", Proceedings of the VIIth International Conference on Megagauss Magnetic Field Generation and Related Topics, Sarov, August 1996, pp 280-285