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NUMERICAL SIMULATION OF EXPLOSIVE MAGNETIC CUMULATIVE GENERATOR EMG-720

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Abstract

In the present paper there are discussed the methods and results of the numerical simulations used in the development of a helical-coaxial explosive magnetic cumulative generator (EMG) with the stator diameter of up to 720 mm. In the process of designing separate units were numerically modeled, as well as the generator operation with a constant inductive-ohmic load. The 2-D processes of the armature acceleration by the explosion products were modeled as well as those of the formation of the sliding high-current contact between the armature and stator's insulated turns. The problem of the armature integrity in the region of the detonation waves collision was numerically analyzed.

Introduction

There is a demand on EMG with high current rise velocity, current and energy amplification coefficients and amplitudes. Such EMG's have several advantages: the simplification of further formation of a submicrosecond meraampere pulse, no necessity to connect several generators into a cascade using transformers and cables, reduced requirements to the stored initial energy, which is more expensive as compared to the generator produced energy. Development of the new helical-coaxial generator EMG-720 was aimed at the above mentioned. Partially EMG-720 is described in the present paper. The task of obtaining 100 MA current pulse in 20 nH load with doubling time at the final stage of 20-30 μs resulted in the generator design represented schematically in Fig. 1.

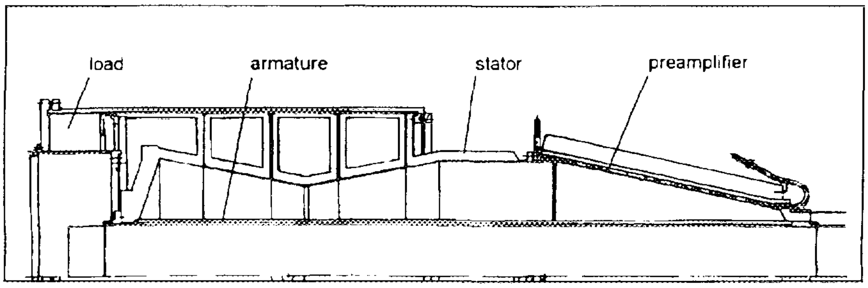

Fig. 1. Schematic of the EMG-720 generator.

The generator stator coaxial part is collected of two cones. The detonation waves propagation in the direction of collision allows to increase the armature active length by a factor of 2 and increase the value of dL/dt and the load voltage. The armature cones' length is limited by the ultimate tension degree of 2 prior to the formation of cracks in the armature metal tube. It is worth noting that such a method of the armature active length extension is simpler and more cost-effective in comparison with that of the simultaneous axial initiation.

The generator aluminum armature tube was 35 mm thick, 390 mm external diameter and 2.1 m length. To define the dimensions there were solved the problems of (1) the effective getting the HE energy due to a considerable tube weight, and (2) reaching a comparatively high velocity to reduce the diffusion losses of the magnetic flux, and (3) providing for the required current duplication time at the final stage.

The HE charge is collected from ring-shaped sections. The hole in the charge was filled with the uniform aluminum blocks reducing the explosion products relaxation into the inside. The armature design ensured the shell velocity of 1.8 km/s.

The stator helical part is comprised by the turns of the coated 10 mm (14 mm) copper wires, using the maylar film. The helix is sectioned. The number of wires changes in the range of 1-64 and is duplicated from section to section. The initial inductance of the helix is nearly 54 µH, the length is 65 cm. The helix diameters at the sides are 720 mm and 420 mm.

The cone shape of the helix provides some advantages. It makes it possible to join the helix with the coaxial part of the stator of a large diameter and have the highly inductive single-wire long section. The said shape also allows to lessen the peak electric voltages between the coil and armature in the generator working volume, as well as the losses caused by the magnetic flux cut-off's due to non-coaxialities and inaccurate assembling [2]. A high initial inductance of the generator leads to the considerable experimental current and energy amplification coefficients, 500 and 120 respectively.

Numerical simulation of the generator.

To define the armature extension shape, the 2D MHD modeling and experimental research were employed. To know the armature shape is necessary to choose the stator cone sizes and provide the simultaneous shot. The data agreement is quite good in this case. The computed flying shell shape is shown in Fig.2.

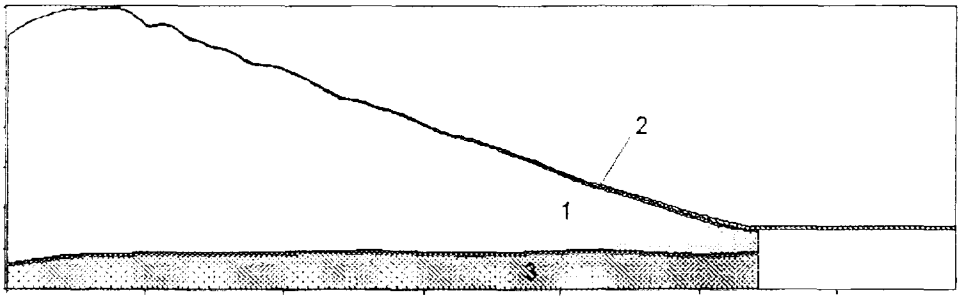

Fig.2. Schematic of the flying armature.
1 - HE, 2 - armature, 3 - aluminum blocks.

The shell surface disturbances at very high tension correspond to more then double one and so are negligible.

Gas dynamics in the area of the detonation waves collision was researched because of the risk of the radial cutting of the tube with the cumulative jets. Various designs of this unit were numerically investigated, namely: incorporation of the air gap between the charges; that of the foam-filled or aluminum-filled one. In Fig.3 the gas dynamic image of the armature deformation is given, when the gap between the rings is filled with the foam as dense as 0.5 g/ccm. The lowest detonation nonuniformity in this place was reached in case of a partial filling of the volume with aluminum and the remainder with the foam. In the experiment the cracks were not found.

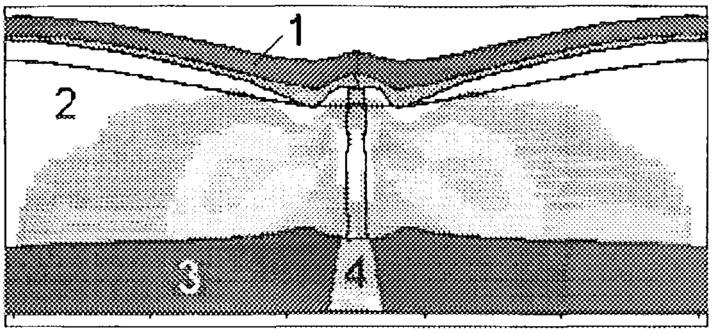

Fig. 3. Schematic of the armature deformation.
1 - aluminum shell, 2 - HE, 3 - aluminum blocks, 4 - gap.

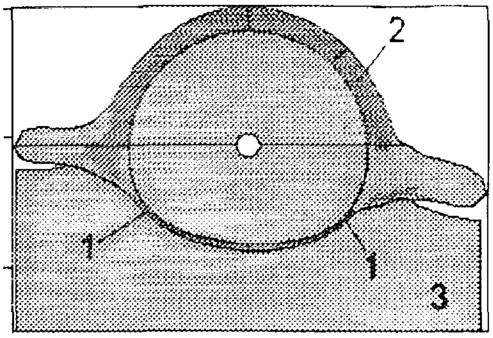

Fig. 4. Schematic of the wire insulation damage.
1 - contact, 2 - insulation, 3 - cone armature.

There was paid a great attention to the area of the sliding contact between the helix and armature. A great thickness of the high-voltage insulation impedes the formation of the low ohmic contact and may become the main source of the magnetic flux losses. In Fig. 4 there is given the picture of damaging the 2 mm thick maylar insulation of the separated copper wire by the aluminum liner.

The contact is formed in 2.23 μs after touching the insulation. The research revealed that the contact formation in case of a copper armature is faster and most probably more reliable.

In the generator current calculations the armature dynamics accounting for the magnetic field pressure was modeled using a simpler and more fast operating 3/2 D MHD code based on the method of independent cross sections [1]. In this case all the calculation methods and experiment as well proved to be in good agreement. In Fig.5 there is given the calculated EMG-720 inductance plot. In the final stage $dL/dt=-1.3\cdot10^{-3}$ Ohm.

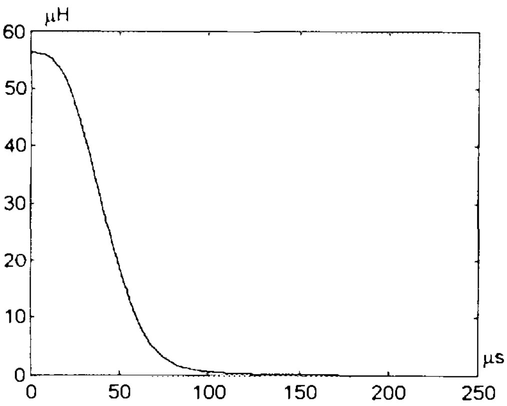

Fig.5. Calculated generator inductance.

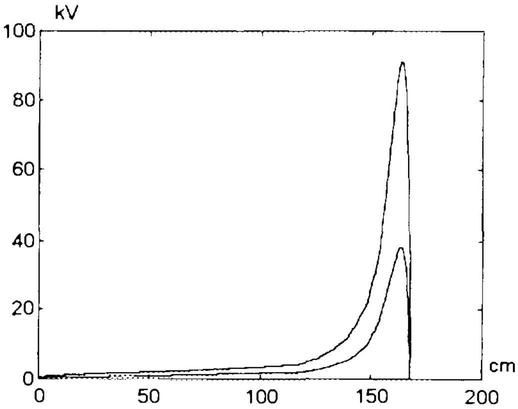

Fig.6. Calculated helix-armature voltage distribution.

By the known generator inductance distribution along the length, $L(z,t)$, it is possible to derive the voltage distribution between the armature and helix: $V(z,t) = d(L(z,t)\cdot J(t))/dt$ (with no account to the ohmic resistance).

In Fig.6 the calculated electric voltage plot is shown at the moment of the absolute voltage maximum in case of 37 kA and 75 kA powering. Choosing the wire insulation, we were oriented to peak value of the voltage at the maximum possible powering.

The considerable generator size and design peculiarities made us to consider the possibility to manufacture at least the stator coaxial part of ordinary quality steel to decrease the material cost and simplify the technology. Stator's massive units manufacturing of copper or only coating with copper are unnecessary. Due to not widely spread steel application for such purposes in the high current equipment there was calculated the nonlinear diffusion of the pulsed magnetic field of megagauss amplitude into the steel having the initial magnetic permeability of $\mu(H_0)\approx3000$ and conductivity reducing in the process of heating. The calculation proved that similarly to the case of linearity as to a diamagnetic metal the magnetic field diffusion depth is $\sim\sigma^{-1/2}$; and the generator performance degradation in not expected when replacing copper with steel in the coaxial part. In Fig.7 there is represented the calculated magnetic induction distribution in copper, steel and aluminum at the exponential growth of the boundary field up to 0.5 MGs with the effective time of 30 μs.

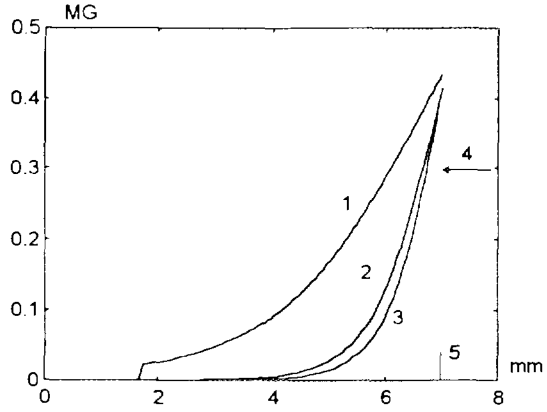

Fig. 7. Calculated magnetic induction distribution.
1 - steel, 2 - aluminum, 3 - copper,
4 - diffusion direction, 5 - metal boundary.

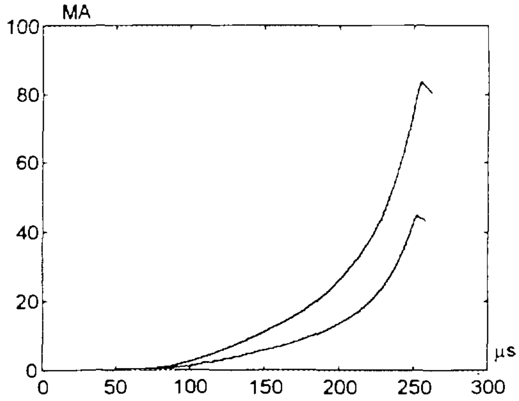

Fig. 8. Calculated generator currents with 20 nH load and37 kA and 75 kA powering.

The calculated generator currents in case of the operation with 20 nH load and 37 kA and 75 kA powering are shown in Fig. 8.

Conclusion

As was expected, the initial experimental results proved to be some lower than the numerical prognosis predicted which leaves great opportunities for the further development. First and foremost, we are planning to research the quality of the sliding contact because the critical flux losses were revealed in the helix. It would be useful to replace the aluminum armature with the copper one. This will somehow increase the generator inductance and upgrade the contact quality. We believe that the design potential in terms of the current is nearly 100 MA.

[1]. Pavlovskii A.I., Lyudaev R.Z., Boyko B.A. et al. Numerical model for Helical Magnetic Cumulation Generators. In: Megagauss Fields and Pulsed Power Systems. Ed. by V.M.Titov and G.A.Shvetsov. Nova Science Publishers, NY, 1990, p. 233.

[2]. Mironytchev P.V. High Temperature, V. 33, N. 4, 1995, pp. 635-640.