STUDY OF MAGNETIC FIELD DISTRIBUTION IN VECTOR-INVERSION GENERATORS

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Abstract – The results of experimental and theoretical modeling of spatial and temporal distribution of magnetic field induction inside a vector-inversion generator of cylindrical configuration with meander-shaped profiled buses (Fig. 1) are presented. The influence of a ferrite magnetic core on the output characteristics of generators is analyzed. The obtained results allow one to estimate a part of the energy localized in the magnetic field and are also necessary for technical modeling of vector-inversion generators.

INTRODUCTION

A vector inversion generator (VIG) is a compact device that stores electrical energy at a single, relatively low voltage and discharges the stored energy in the form of a short (about 1 ns) electrical voltage pulse that is tens of times greater than the charging voltage [1]. A distinctive feature of the vector-inversion generator design, which distinguishes it from other high-voltage pulse generators, is the absence of elements that perform decoupling of the capacitors of the primary low-voltage and secondary high-voltage circuits. The generator is switched using a spark gap. The finished generator thus consists of only a few parts, and at the same time has good weight and size characteristics.

In this paper, vector-inversion generators of a new, improved type proposed in patent [2] are investigated. The main difference from a conventional generator is the profiling of strip lines in the form of a meander so that the inductive and capacitive parts of the line become spatially separated, which leads to an increase in the wave resistance of the line several times, and as a result, has a positive effect on the energy characteristics of the device.

The principle of operation of the vector-inversion generator is as follows: when the spark gap is triggered, an electromagnetic wave begins to spread between the active and passive lines of the generator. In this case, the electric energy is converted into the energy of the magnetic field, and the electric energy of the coaxial capacitors, which are connected in series. After reflection from the open ends of the line (Fig. 2, a), the energy of the magnetic field in it begins to convert back into electric energy, and the wave in the active line changes polarity (Fig. 2, b). When the reflected wave reaches the point where the switch is installed, the voltage between the beginning and end of the spiral reaches its maximum value. Free damped oscillations arise in the electromagnetic system formed by the distributed capacitance and inductance of the spiral plates that form the active and passive lines, generating a magnetic field both in the elements of the generator's design and in the space surrounding it. This pulsed magnetic field affects the course of electromagnetic processes in the plates and magnetic circuit of the generator itself, as well as the electromagnetic compatibility of this generator with technical objects located nearby.

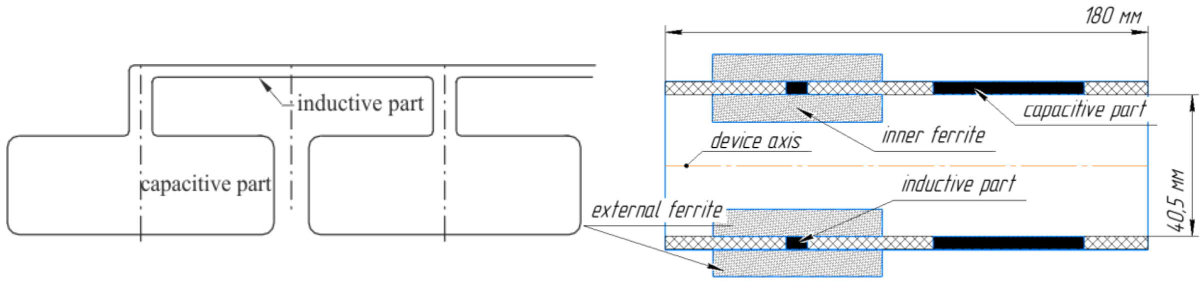

Figure 1 Profiled line view (left) Generator layout in section along the axis (right)

Now, there is only one work [3] devoted to the study of magnetic field distribution in generators of this type. However, it presents only the results of experimental modeling of the pulsed magnetic field distribution in time. For technical modeling of vector-inversion generators, a model is required that allows theoretical modeling of the spatial distribution of magnetic field induction, allowing at the stage of generator design to reduce energy losses and thereby increase the generator efficiency.

One of the mechanisms for controlling the spatial configuration of magnetic field induction inside and outside the vector-inversion generator is the placement of a ferrite magnetic core (Fig.1, right).

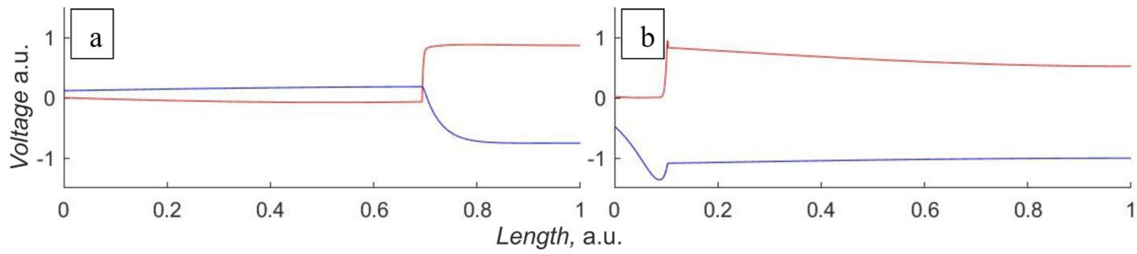

Figure 2 Profiles of the electromagnetic wave at the first (a) and second (b) reflection from the free ends (dependence of voltage (y) on line length (x) in dimensionless form)

Experimental study and theoretical modeling were performed for three cases of magnetic circuit configuration: without ferrites, only internal ferrite rings, ferrite rings inside the generator and rods outside it.

EXPERIMENTAL STUDY OF THE DISTRIBUTION OF THE MAGNETIC FIELD OF A FLOWING CHARGE

The charge flowing through the strip line spirals creates a magnetic field inside the spiral generator. Experimental determination of the distribution of this field over time is necessary to understand the portion of energy that goes into the magnetic field, as well as to test and calibrate theoretical models of the magnetic field distribution in and around the generator.

To obtain experimentally a graph of the magnetic field induction dependence on time inside the vector-inversion generator, an inductive sensor was made, which is a coil of copper wire, the ends of which are connected to an oscilloscope. The coil diameter is 40 mm, its inductance is 0.4 μH. Integration of the obtained dependence of the EMF induced on the coil with normalization to its inductance and radius allows us to obtain the dependence of the magnetic field induction on time for the magnetic field in the plane of the current-carrying coil. Figure 3 (left) shows the experimentally obtained graphs of the dependence of the magnetic field induction inside the generator (under the inductive part of the spiral line) on time for three cases of switching on the magnetic circuit. It follows from the graphs that the amplitude value of the magnetic field induction inside the spiral generator decreases when the magnetic circuits are turned on, which indicates a decrease in the portion of energy lost in the magnetic field.

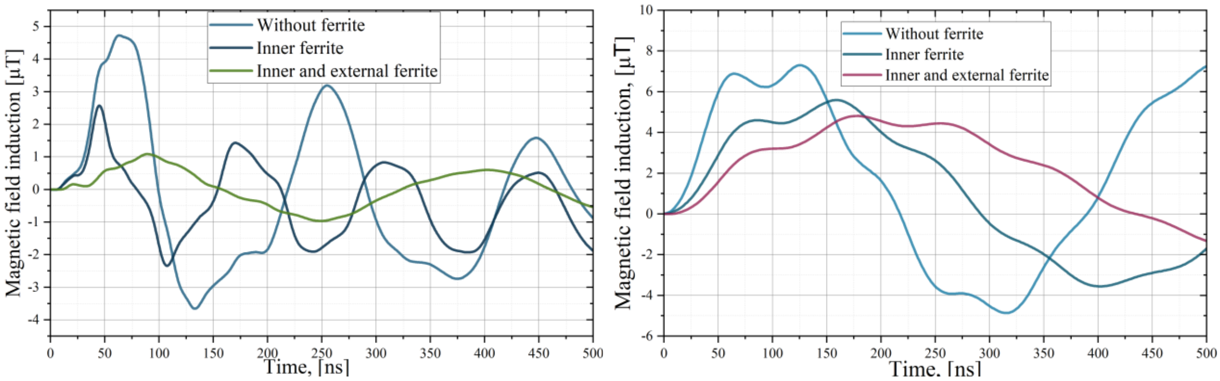

Figure 3 Dependence of magnetic field induction on time: (left) inside of the generator, (right) by the spiral line

The values of the generator output voltage obtained for the VIG in three variants of the magnetic circuit connection were also integrated (Fig.3, right). The calculated graphs of the dependence of the magnetic field induction created by the spiral leakage current on time were obtained. To this calculated leakage current field is added the stray field coming out of the slits of the strip lines of the spiral, and the field obtained is the experimentally measured field in Fig. 3, left.

MODELING THE SPATIAL DISTRIBUTION OF THE MAGNETIC FIELD IN THE GENERATOR

For theoretical modeling of the magnetic field distribution in a spiral generator, the software package for modeling using the finite element method “Finite element method magnetics, FEMM” was selected. The magnetic permeability of the *M200VNP* ferrite we selected is 200. The coercive force of the ferrites is 80 A/m, the residual magnetic induction is 0.25 T (at H=800 A/m). The conductivity of the ferrite within the model is zero. Using this data, a nonlinear B-H dependence for soft magnetic material was specified in the program. The calculation area is defined by the boundary condition for the flow parallel to the boundary (vector potential A = 0). Figure 4 shows models of the spatial distribution of the magnetic field induction modulus for three cases of inclusion of a ferrite magnetic core: without ferrites (a) (the program is set to zero magnetic permeability), with ferrites inside (b), with ferrites inside and outside (c).

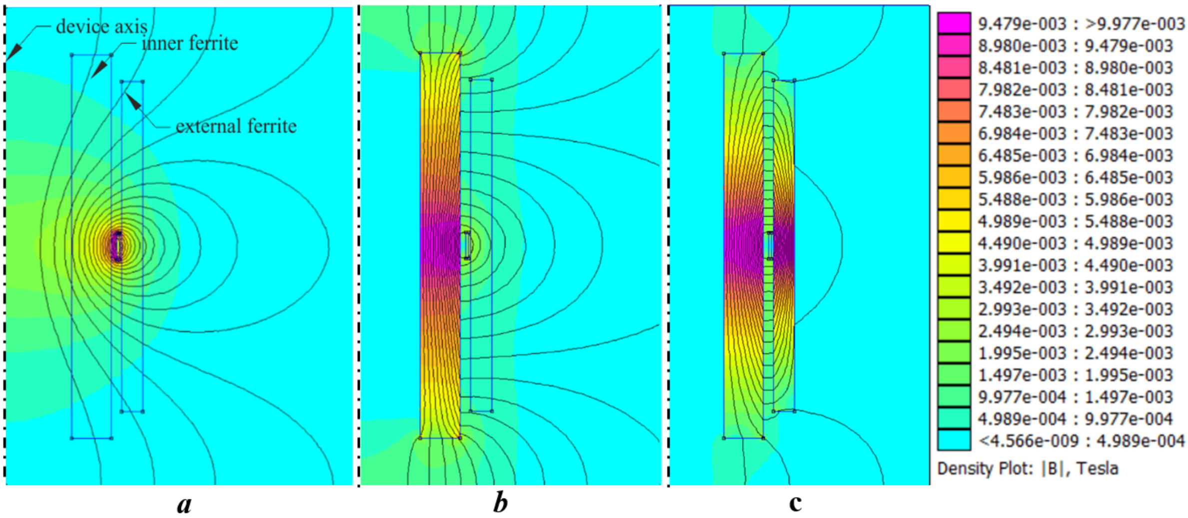

Figure 4 Models of spatial distribution of magnetic field induction in a generator

Figure 5 shows graphs of the values of the magnetic field induction module at points along the line from the generator symmetrical axis to its outer end, passing through the current-carrying part of the generator. When adding a ferrite core, the induction module of the magnetic field concentrated in it increases sharply. As follows from the analysis of experimental data, the obtained numerical solution to the problem of magnetic field distribution in a spiral generator is sufficiently accurate and can be used in modeling and calculating end devices.

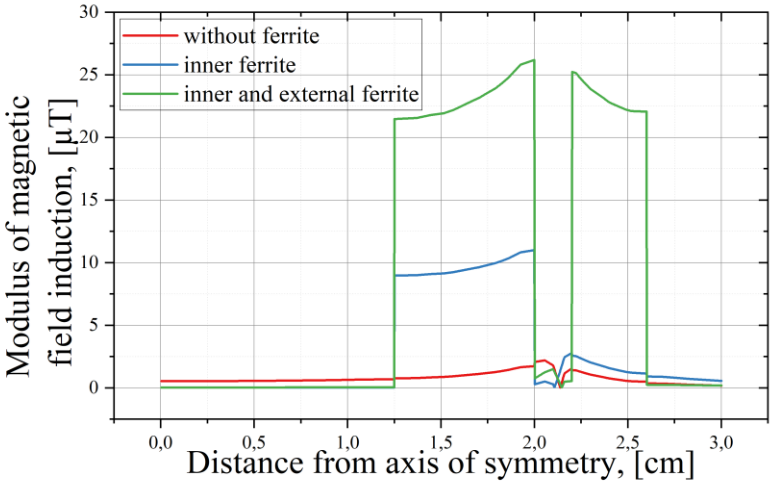

Figure 5 Distribution of magnetic field induction along the line from the generator axis to its outer end

CONCLUSION

The resulting models further confirm that the presence of a ferrite magnetic core leads to the accumulation of a magnetic field near the inductive part of the spiral line, reducing magnetic losses and increasing the efficiency of the device. The amplitude value of the magnetic field induction inside the spiral generator decreases when the magnetic circuits are turned on, which indicates a decrease in the portion of energy in the magnetic field losses. The data obtained will be used for engineering modeling of vector-inversion generators with the highest efficiency.

LIST OF REFERENCES

1. R. A. Fitch and V. T. S. Howell, “Improvements in or Relating to Pulse Generators,” GB Pat. 975911, H 03 k.
2. E. I. Palchikov, “Spiral High Voltage Pulse Generator,” Application 2021120420 A, IPC H 05 G 1/24. Appl. 09.07.2021; Publ. 09.01.2023, Bull. No. 1.
3. O.L. Rezinkin, Physical modeling of electromagnetic processes in a flat spiral high-voltage pulse generator with a ferrimagnetic core // Bulletin of the National Technical University "KhPI". - Kharkov: NTU "KhPI", 2011. - No. 4. - P. 94-102.
4. E. I. Palchikov, A. M. Ryabchun and A. G. Paraskun. Spiral High-voltage Pulse Generator With Spatially Separated Inductive and Capacitive Parts. Journal of Applied Mechanics and Technical Physics, 2024, Vol. 65, No. 4, pp. 602–608. DOI: 10.1134/S0021894424040023