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Pulsed power: methods and applications

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G A Mesyats. *Pulsed Power and Electronics*[1] (Moscow: Nauka, 2004) 704 pp, ISBN 5-02-033049-3

Pulsed power and the accompanying high-power electronics is a recently born and rapidly expanding branch of technical physics. The scientific foundations of pulsed power are formed from the fundamental fields of physics: electrodynamics of fields and particles, quantum physics, and the structure of matter, as well as from numerous applied fields: the theory of electric circuits and generation of high-power electric pulses, the formation and transportation of high-density energy fluxes in long power lines and using charged particle beams, and the interaction of charged particles with gases and condensed matter.

Even this short list of fields clearly shows that the publication of G A Mesyats' scientific monograph, dealing with most of these branches of physics, is an important event in electrophysics. The publication of this monograph is a direct echo of the fact that the high-prestige international Global Energy prize was awarded last year to Gennadiĭ Mesyats (Russia), Nick Holonyak (USA), and Ian Smith (USA) for outstanding theoretical, experimental, and applied research in energy generation. In this connection we feel justified in saying that this monograph reflects the important contribution of the Russian school of electrophysics to international science and technology.

This monograph is the first successful attempt at systematic presentation of both the physical foundations and the technical solutions of a huge and important branch of modern applied science. It is necessary to say that monographs of this calibre, devoted to a very broad field of science, are very rare in the world literature. As examples from physics we can refer to the well-known monographs of Charles Kittel, *Introduction to Solid State Physics*, K Shimony, *Physical Electronics*, and M Born and E Wolf, *Principles of Optics*. Hopefully, G A Mesyats's monograph *Pulsed Power and Electronics* will take its well-deserved place in this list.

[1] The English edition of the book, entitled *Pulsed Power*, will be published by Springer Science + Business Media (former Kluwer Academic merged with Springer-Verlag) in October 2004.

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The monograph consists of nine large parts that comprise 32 chapters. Each chapter ends with a bibliography.

Part I, Fundamentals of Pulsed Power Technology, very briefly gives an outline of the techniques for describing pulsed signals, long transmission lines, the principles of generation and transformation of short high-voltage pulses using capacitor or transformer circuits, and pulse-forming lines. This part provides only a brief list of the main principles of pulsed power technology and does not attempt to clarify the subtleties of the functioning of various electrical devices. A highly skilled reader familiar with the fundamentals of electric circuit physics is simply reminded of the scientific concepts and the main terminology: the frequency transmission band and the impedance of a transmission line, capacitive and inductive energy storage, addition and multiplication of voltages, pulse-forming lines, etc. The main formulas used in the subsequent parts of the book are also given in Part I.

Part II of the monograph is devoted to certain aspects of the physics of electrical breakdown in gaseous and liquid dielectrics and to the specifics of currents in gases. A special chapter deals with processes that take place in the vacuum gap breakdown. We need to emphasize that it was precisely in the physics of vacuum breakdown that the research of Mesyats and his team played an outstanding role: they discovered a new physical phenomenon — the explosive electron emission. The subsequent analysis of this phenomenon made it possible to reveal its fundamental role not only in the vacuum but also in a gas high-current discharge. The author of the monograph introduced a new concept, an ecton (from ECton for Explosive Center) which stands for a nonstationary compact object formed on the surface of the cathode and emitting electron fluxes of extremely high density (on the order of 10^8 A/cm^2).

Part III describes specifics of using coaxial lines in high-power pulse systems, including pulse-forming lines with water insulation and vacuum lines with magnetic self-insulation.

Readers with engineering backgrounds will definitely be interested in studying Part IV, Gap Switches, which presents in considerable detail and with structural specifics the operation of a broad range of modern switches. Here we find a description of the physical principles for triggering switches of this type and an array of drawings of various designs: trigatrons, laser-triggered and electron-beam-triggered spark gaps, megavolt multielectrode spark gaps, hydrogen thyratrons, pseudospark switches, liquid switches, etc.

The central problem of pulsed power engineering — the generation of high-power electric pulses — is the subject of three full parts of the monograph. Specialists working in this field will find in these parts a huge number of examples of pulse generator design. Even a brief enumeration of generator types discussed in the monograph would take too much space; we therefore limit ourselves to mentioning only the chapter

devoted to generators with solid-state switching. This seems to be the most complicated field in pulsed power; it is also the field in which the most impressive results have been achieved. The complexity lies in the fact that the physical effects used for pulse generation are in themselves far from trivial. We mean here the use of ferromagnetic and semiconductor materials for switching and breaking high currents, as well as nonlinear phenomena in long transmission lines. Even a brief exposition of such methods of electrical energy compression within a single volume is the first in the scientific literature.

However, it is not enough to generate an electric power pulse; the pulse must be delivered to the point of consumption. Electromagnetic energy can be efficiently transported as a directed flow of charged particles — electrons and ions. They can be accelerated by electric fields to very high energies and directed to the right place. Part VIII of the monograph, consisting of four chapters, is devoted to the methods of production and transportation of dense electron and ion beams. The content of this part is based mostly on the results of many years of theoretical and experimental studies at the world-famous scientific school headed by Mesyats.

The concluding and largest part of the monograph is devoted to numerous applications of pulsed power. It includes generation of high-voltage power pulses of X-ray, optical, and microwave radiation, and the formation of picosecond high-voltage electric pulses. The appropriate chapters of this part give the reader a brief exposition of the physical phenomena that are the basis for producing radiation of specific types. These are the emission of bremsstrahlung and characteristic X-ray radiation, the creation of inverse population of quantum levels in atoms and molecules of the lasing medium for generation of laser radiation, and the coherent interaction of charged particles with electromagnetic waves in the microwave frequency range. This part of the volume gives designs and detailed specifications of a number of specific systems, some of which possess record physical parameters. Relativistic microwave oscillators, created on the basis of repetitively operated high-current electron accelerators that determine the current state-of-the-art in these sorts of devices, deserve being mentioned separately.

Despite very broad coverage of physically and technologically complicated material, Mestyats's monograph contains, at least briefly, all the information required for the reader. This constitutes the main methodological advantage of the book. Another valuable characteristic is the fact that the main part of the data was obtained under the guidance or with the actual participation of the author of the monograph. This is true not only for the results obtained in two institutes of the Russian Academy of Sciences — the Institute of High Current Electronics (Tomsk) of the Siberian Branch of the Academy and the Institute of Electrophysics (Ekaterinburg) of the Ural Branch of the Academy — but also for the results obtained in a number of laboratories abroad that work in close collaboration with organizations in Russia both at scientific conferences and in the framework of joint projects.

This monograph cannot be classified as a textbook because it would be impossible to answer within one book, even such a voluminous one, all the questions raised by students in the process of training. Nevertheless, the monograph is of great educational and methodological value, which stems from its encyclopedic coverage and an excellent structuring of subject presentation. Experts working in this and adjacent fields of physics will find a considerable amount of reference material and review-type information in this volume. Because of the technical specifics of the book, some mathematical relationships are represented not in the accepted standard manner. For instance, quite a few formulas used most frequently in engineering calculations are given not in system units but in practical units of measurements. Therefore, such formulas typically contain dimensional numerical factors and this implies that all quantities are to be used with the specifically indicated dimensions. However, this inconvenience arises only if you do selective reading: the dimensionality of the variables used is normally clear from the preceding text.

We specially need to commend the high quality of preparation of the manuscript and the visual appearance of the published volume. Cursory browsing failed to reveal any significant errors, and both the text and illustrations merge well with the reading. I expect the monograph, *Pulsed Power and electronics*, to be useful for present and future generations of researchers.