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New Technologies for Particle Accelerators

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ABSTRACT

The article proposes to consider two fundamentally new ways of accelerating charged particles: linear acceleration (LA) of protons on a backward wave (Professor Bogomolov's Accelerator) and wake acceleration of electrons using a proton driver in the Large Hadron Collider (AWAKE project).

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Introduction

The European Strategic Group (ESG) is considering fundamentally new projects to create more efficient and less expensive accelerators and colliders for research. The article proposes two particle acceleration projects based on completely new physical principles: wake acceleration of electrons using a proton driver in the Large Hadron Collider (AWAKE project) and back wave acceleration of protons (Professor Bogomolov's Accelerator).

In fact, in all projects of the last 30 years, the developers of linear accelerators focused on the capabilities of the SCS. In particular:

- in the USA (2006) the world's most powerful proton laser was created - a source of neutrons - SNS (proton energy 1 GeV, power 1.56 MW, length 258 m);
- in the USA (2008-2018) a multifunctional 8 GeV ion DL (L=692 m) is being created;
- The European Community (2010-2018) is designing the ESS neutron complex at the beam of the H-linear proton accelerator with an energy of 1.33 GeV and a beam power of 5 MW;
- China, India, Japan, South Korea are implementing programs based on the creation LAP for fundamental and applied research that determines the future of AE.

In these programs, the accelerators are "single-technology" - all on superconductivity. The creation of these accelerators consumes billions of dollars of resources. Designs of "warm" LA (for ADS), different from traditional schemes, not discussed anywhere. According to the author last known a serious discussion of the problem was at EPAC-96 [1]. The modern scientific literature contains a guiding statement that is widely spread throughout the world community of accelerator technology developers: "in "warm" versions of LA, the efficiency is low, and a small aperture (diameter of the accelerator channel) is a problem in terms of beam losses, which, moreover, are not localized". It is this kind of assertion that forced the bulk of the creators of LAs to develop superconducting (SP/SC) accelerator complexes. As a result, since the beginning of the 1990s, serious analysis and publications on the development of superpower linear accelerators that could be performed on LA structures at room temperature (~300 K) have practically disappeared. This erroneous opinion is completely refuted by the theoretical work of Professor Alexei Bogomolov and the successful operation of the backward wave proton accelerators he created [2].

The Accelerator of Elementary Particles on the Backward Wave of Alexy Bogomolov

Today, more urgent than ever, the task of life support for mankind cheap and reliable sources of energy (electricity and heat) and getting rid of accumulated amounts of radioactive waste and fears associated with the use of nuclear energy. Nuclear power in reactors with a self-sustaining reaction causes a wary attitude towards it both by the population and professionals. Control, maintenance of operability and safety, and management of all processes in subcritical reactors are carried out by beams of high-energy protons. This fundamentally distinguishes subcritical reactors from modern ones reactors and completely excludes Chernobyl-type reactivity radioactive accidents. Instead of maintaining a chain reaction, a subcritical reactor uses additional neutrons from an external source. There are two main classes of such devices. One uses the neutrons given off by a nuclear fusion machine, a concept known as a hybrid of fusion and fission. The other uses neutrons created by the fission of heavy nuclei by charged particles such as protons accelerated by a particle accelerator, a concept known as an accelerator driven system (ADS) or accelerator driven subcritical reactor. In the article "BWLAP's versa SC-Linacs", Professor Aleksey Bogomolov presents the materials of his fifty years of research aimed at creating ADS - an accelerating nuclear installation for industrial use, on the topic of BWLAP (reverse wave linear particle accelerator), in relation to the problem of creating a compact proton accelerator at high-performance linear accelerators. structures of "room temperature" with a clearly expressed inverse spatial harmonic of a high-frequency electromagnetic field propagating against the flow of the accelerated particles [2]. It proves the BWLAP (with water-cooled accelerator structures) advantage over superconducting accelerators in general efficiency (Pbeam/PAC) at analogous energy of protons. Application of BWLAP appropriate in the complexes with sub-critical nuclear reactors for transmutation the radioactive waste (RW) and blowing minor actinides, and to produce nuclear energy. A modular three-dimensional back-wave accelerator producing a huge stream of protons can become a formidable weapon. The BWLAP can provide the regime with a low duty cycle and continuous-wave operation. A group of researchers led by Alexei Sergeyevich Bogomolov developed a technology for accelerating positively charged particles (protons, deuterons) on a backward wave - BWLAP (Figure 1). The essence of this technology is the acceleration of elementary particles by the electric component of an electromagnetic wave traveling in the same direction and at the same increasing speed as accelerated ions. In this case, the source of electromagnetic waves is installed at the end of the accelerator, which is opposite to the injection one, and the wave runs towards the energy flow - thereby the wave (spatial harmonic) is oppositely directed with respect to the direction of the energy flow.

The article by Professor Alexei Bogomolov discusses the achievements in the development of linear accelerators based on highly efficient "thermal" frequency structures, the value of the overall and electronic efficiency and the loss of particles during their acceleration in BWLAP's [2].

Accelerator complexes, if they are implemented according to the reverse wave accelerator scheme with a heat removal system with room temperature water, will provide power in accelerated proton beam ~ 2-3 (30) MW and proton energy 1-10 GeV and will have a huge superiority compared to accelerators based on superconducting structures [2].

Figure 1: Alexey Bogomolov's Mobile Modular 3D Reverse Wave Accelerator

The AWAKE Project at CERN in the Light of Maxwell's Real Electrodynamics

At CERN, for the first time in the world, it has been experimentally proved that the acceleration of an electron beam in the plasma by means of a proton driver is possible. The team behind the Advanced Proton Driven Plasma Wakefield Acceleration Experiment (AWAKE) at CERN in Geneva has been working since 5 years after CERN approved the project in 2013. In an interview with the project manager AWAKE Edda Gshwendtner "This is the fantastic: the new method of particle acceleration works " explains the essence of the experiment "In the classical scheme, the electron beam in the collider accelerates under the influence of the electromagnetic field. In our experiment, a beam of protons flies in the plasma it creates a wave and thereby ensures the acceleration of the electron beam that follows. The beam of electrons with an the energy of 19 MeV flew in the plasma ten meters and increased energy to 2 GeV, that is, more than 100 times. This means that the average acceleration rate was 200 MeV / m." [3]. The experiment was carried out by the AWAKE collaboration and scientists from the Budker Institute of Nuclear Physics, Siberian Branch of the RAS (INP SB RAS). Traditional accelerators use what are known as radio-frequency (RF) cavities to kick the particle beams to higher energies. This involves alternating the electrical polarity of positively and negatively charged zones within the RF cavity, with the combination of attraction and repulsion accelerating the particles within the cavity. By contrast, in Wakefield accelerators, the particles get accelerated by "surfing" on top of the plasma wave (or Wakefield) that contains similar zones of positive and negative charges. Allen Caldwell, spokesperson of the AWAKE collaboration said, "Wakefield accelerators have two different beams: the beam of particles that is the target for the acceleration is known as a 'witness beam', while the beam that generates the Wakefield itself is known as the 'drive beam'. AWAKE is the first experiment to use protons for the drive beam, and CERN provides the perfect opportunity to try the concept. Drive beams of protons penetrate deeper into the plasma than drive beams of electrons and lasers. Therefore, Wakefield accelerators relying on protons for their drive beams can accelerate their witness beams for a greater distance, consequently allowing them to attain higher energies." However, the use of charged protons as a driver for electron acceleration, in comparison with photons, has one more advantage. It consists in the appearance of an electrodynamics longitudinal force that effectively accelerates the flow of electrons during the motion of the proton beam. This force electromagnetic interaction can be characterized by the magnitude of the potential change $\bar{A}$ and the wave function of the particle. The interaction was discovered in 1959 in the experiments of Aronov-Bohm.When an electron moves near a long solenoid with a current, the trajectory of the electron changes, although the magnetic field outside the solenoid is zero (**H** = 0), when there is no current in the solenoid, the trajectory of the electron remains unchanged [4]. Professor R. Feynman explains this effect by the interaction of a particle with a vector potential $\bar{\mathbf{A}}$ [5]. The experimentally discovered phenomenon of the force interaction of moving electrons with the field of vector potential A in the experiments of Aharonov-Bohm was also confirmed in later experiments of Japanese scientists in 1986 [6]. In the course of the experiments, a change in the phase of the wave function of a moving charge was found in the absence and presence in the investigated space of the field of the vector potential $\bar{\mathbf{A}}$, in the complete absence of the magnetic field **H** in this space. Positive experimental results corresponded only to the single-valued value of the vector potential current. The change in the phase of the wave function by the vector potential $\bar{\mathbf{A}}$ is determined by the expression:

$$\Delta\varphi = q / \hbar \int \bar{\mathbf{A}} ds, \qquad (1)$$

where the integral is taken along the trajectory of the particle. The Aharonov-Bohm experiment forces us to reconsider the well-established ideas about some transverse magnetic forces of Lorentz and recognize the presence of longitudinal forces of magnetic interaction. The existence of an electrodynamic longitudinal force is confirmed not only by the Aharonov-Bohm effect, but also by the wakefield acceleration of the electron flux in the collider by a beam of relativistic protons. The mechanism of this wakefield acceleration by a charged proton beam differs from the wakefield acceleration of electrons by laser radiation. To explain the nature of the electrodynamic longitudinal force, it is necessary to revise the equations of Maxwell's electrodynamics. Maxwell mistakenly applied the Ostrogradsky-Gauss theorem not only for resting charges, but also for moving ones (Gauss's theorem is one of Maxwell's equations). As a result of this arbitrary assumption, the dynamic state of moving electric charges is simply replaced by their static state. Coulomb's law is valid only for stationary charges [7]. Maxwell himself pointed out the difficulties with his the equations when unclosed electric currents and the individual elements of the current. These difficulties lie in the fact that for the open currents alone, non-zero spatial derivative rot$\bar{A}$ = H of vector potential $\bar{A}$ cannot determine it completely. It revealed the existence of yet another non-zero spatial derivative div$\bar{A} \neq 0$ of the vector potential $\bar{A}$. In general, the vector potential $\bar{A}$ can be represented as the sum of the potential and the vortex components of $\bar{\mathbf{A}}$r + $\bar{\mathbf{A}}$p. It turns out that a rectilinear infinite current does not create a scalar magnetic field, and an element of a current of finite length creates both a vector magnetic field **H**r = rot **A**r and a scalar magnetic field **H**p = -div **A**p [8]. The expression for the electromagnetic energy flux density (Poynting's vector) has the form:

$$\mathbf{S} = (\mathbf{E} \times \mathbf{H}\mathrm{r}) + (\mathbf{E} \times \mathbf{H}\mathrm{p}) \qquad (2)$$

Changing the scalar magnetic field equivalent to the formation of electrical charges, which change in turn generates an electric potential field. Based on experimental results, it is proposed to abandon the Lorentz calibration, but instead take the expression for the electromagnetic energy density in the form [9]:

$$\mathbf{S} = -\operatorname{div} \mathbf{A} - \lambda\varepsilon 0\mu 0\, d\varphi/dt \qquad (3)$$

Obviously, the potentials introduced in this way allow considerable flexibility in the use of Maxwell's equations. In the classical case, S = 0 is assumed. When using gauge (3) at λ=0, the Coulomb gauge is obtained, and at λ=1 we have the Lorentz gauge. If we do not assume that the expression for S is equal to zero, then at λ=0 the scalar field acquires the meaning of a new longitudinal magnetic field. Correction of Maxwell's equations electrodynamics based on the recognition of the additional scalar magnetic field, acting along the direction of the current, which creates the longitudinal force in addition to the transverse Lorentz forces [10].

Conclusion

Proposed for consideration by the European Strategic Group (ESG), new physical methods of particle acceleration can significantly increase the efficiency of charged particle accelerators, while significantly reducing the cost of their manufacture and operation.

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