R&D PROGRAM ON YEREVAN LINAC TEST FACILITY*

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Abstract

R&D program is devoted to the electromagnetic radiation processes arising in the interactions between moving charged particles ensembles and complex boundary structures.

It will be investigated the mechanism of wake-waves formation as well as the influence of electrodynamics properties of structures on the energy exchange between the particles and radiated fields. The program includes the development of asymptotic methods of solution of the Helmholtz-Maxwell equations and the construction of the "membrane" functions of considered structures. Since the fields radiated in these structures exert a "reverse" effect on the particle ensemble, during the investigations there will be developed the alternative method to obtain self-consistent problems solutions. The method is based on the development of heuristic criteria of step-wise approximation in small space-time intervals.

The objects pursued in the series of planned experiments on the Linac Test Facility (LTF) are as follows:

- the forming of a electron bunch ensemble with a given charge distribution;
- the measurement of radiated fields ;
- the measurement of an ensemble structure.

Introduction

The radiation of charged particles interacting with a medium is due to well known (Cherenkov, Transition Radiation, Diffraction Radiation) effects. Most of the works performed in this field concern the radiation of a point-like charge moving in a medium or structure with relatively simple boundary conditions. Also insufficiently are studied the aspects of the construction of self-consistent problems solutions. Interest to these problems is not accidental, since the most topical problems in the present-day accelerator physics are wake-waves excitation and their "reverse" effect on particle ensembles generating these waves, as well as the processes of energy transfer between the particles and generated fields.

Turning to the experimental aspects it should be noted the following principal problems to be solved in design and performance of experiments. A first problem concerns the determination of the structures electrodynamics properties. Here are used the conventional methods of microwave measurements. A second problem - measurement of the particle ensemble with given parameters - also is quite successfully solved using the accelerator physics. And finally , a third problem - measurement of the particle ensemble structure before and after radiation. Solution of these problems includes the determination of the longitudinal and transverse charge distribution functions, particles energy- and space-time characteristics, etc. In this case realization of experimental investigations will require adaptation of well-known effects to the specific problems.

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Main Goals and Preliminary Studies

The radiation of a moving particle ensemble interacting with a medium contains information on the ensemble structure and the medium properties as well as on the process of the particles interaction with the medium. From this standpoint of particular interest is the radiation in the RF band of wavelengths, since in this case the length of radiated waves is comparable with the characteristic dimensions of the structure and particle ensemble. More interesting are the limited structures - waveguides and cavities - because these possess a strong frequency dispersion.

The proposed investigations intend to create a motivated method for the construction of a real pattern of the radiated fields in complex-form structures. The major difficulties here arise in determination of a complete set of eigenfunctions because of, say, impossibility to separate variables in the Maxwell equations. Within the given program the asymptotic methods of solving the Helmholtz-Maxwell equations will be developed.

A significant part in the radiation process may be played by radiated quantum recoil. This may result in deformation of the structure of the radiated particle ensemble. Account of this factor also is the object of the proposed program and implies formulation of self-consistent problems based on the Bolzmann-Maxwell equations. The difficulties encountered in solution of these problems can be overcome through the development of applicability criteria for the "given current" method in small space-time intervals wherein the laws of motion and the structure of particle ensemble can be considered given.

The participants of the proposed program have been engaged in theoretical and experimental studies of problems concerned with charged particle radiation in waveguides and cavities as well as the acceleration new methods. In the course of these studies it was developed and used the methods of field construction in waveguide-cavity structures at arbitrary motion of a charge and in the presence of spatial-inhomogeneous filling.

The team has studied, in particular, the transition, Cherenkov, "parametric" and "closed" radiation [1] in a waveguide. Conditions have been determined under which one can observe the Brewster effect in a waveguide [1]. The team has studied in detail the mechanisms of excitation and formation of wake-waves by particle ensembles in the regular waveguides with a complex and nonconventional cross-sections [2,3].

Main Topics of the Program

Here we can see three important problems: the forming of an electron bunch ensemble with a given charge distribution; the measurement of radiated fields in waveguides and cavities; and the measurement of an ensemble structure.

To solve the first problem, we suppose immediately after the LTF electron source ahead of the injector section of the linac to install a special part - pre-injector - which represents a multi-cavity multi-frequency choppers and bunchers on the beam. By setting certain phase-amplitude and frequencies relations between the pre-injector cavities we can form a required structure of an ensemble of electron bunches which further will be accelerated in the linac up to necessary energy[4].

To measure the radiated fields in the structure by electron bunch ensembles, it is supposed to use the witness bunch (the probe charge) from a second linac.

Highly important, if not crucial, is the problem of determination of the bunch ensemble structure - charge distribution and bunch duration. To solve this problem, we suggest to apply the methods based on the transition radiation.

Wake-wave excitation

This Program comprises investigation of wake-wave excitation in complicated waveguide (cavity) structures and optimization of these structures' geometry of maximum energy take-off from the driver beam and its transfer to the accelerated beam. It is implied to study structures filled with periodically inhomogeneous dielectric. If we choose the filling parameters such that the Brewster condition in the waveguide could be satisfied, and simultaneously demand fulfillment of Vavilov-Cherenkov condition, then, as is shown by calculations performed [5], we can achieve high accelerating gradient. This means that LTF electron beam will be able to generate the field with a strength higher than 100 MeV/m in such structure.

This cycle implies the problem of provision of increasing the transformation ratio in the scheme of two-beam acceleration. It is known that if the bunch charge distribution function is symmetric, then the transformation ratio cannot exceed 2. It is known also that wake-fields with a maximum transformation ratio will be generated by a driving bunch provided that all the particles of the bunch lose the same energy. Such bunches are ones with linear, piecewise-linear, piecewise-exponential etc. longitudinal distribution. We have shown [3] that more applicable in terms of realization is a scheme using a train of driving bunches. In particular, in the single-mode approximation the particles of N point-like driving bunches lose the same energy if the distance between the bunches is equal to half-length of the excited wave, and the number of particles in the n-th bunch is $N_n = N_1(2n-1)$. In that case the transformation ratio will be proportional to $2N$. The advantage of this version is that the total number of particles giving energy to the wake-field can be considerably increased with a reasonable number of particles left in each bunch. Note that the system of the LTF beam formation [4] before the linac's injector section - pre-injector - makes it possible to form bunch trains with required distribution of particles from bunch to bunch.

It is also planned to investigate excitement of a separate cavity and cavity set optimized in such a way that the resulting accelerating gradient would also be higher than 100 MeV/m [6]. This stage also includes experiments on investigation of structures with complex cross-section [2]. It will be determined complete sets of proper membrane functions of regular waveguide with complex cross-section in the form of two or more intersecting circumferences of different radius, intersecting ellipses, etc.

Determination of charged bunch ensemble structure.

The Program also includes problems dealing with determination of ultrashort charged bunch ensemble fine structure (charge distribution function in a bunch, from bunch to bunch, bunch duration, etc).

We have shown that the time dependence of transition radiation burst intensity is unambiguously connected with charge distribution in the bunch [7]. This fact allows us to suggest a method of determination of charge distribution function in the bunch also including single ones, with the use of specially developed research technique for ultrashort light pulses [8].

A second way to solve this problem is based on determination of the spectral composition of transition radiation and recovery of the most probable shape of charge distribution and bunch duration [9, 10].

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