Summary of the Working Group on Structure-Based Acceleration

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Abstract

The working group on structure-based accelerators had an expansive mission, consisting of externally powered structures of high frequency, novel material and/or novel structure design, wake-field (excluding plasma) accelerators, and inverse radiative process accelerators. Within the context of these themes, discussions were held on the subjects of field gradient, efficiency, and accelerated beam quality, with an eye on technical and experimental issues brought on by the need to experimentally develop these schemes. We discuss here the progress presented in the working group, as well as recommendations for future directions in this area of advanced accelerator techniques.

INTRODUCTION

The notion of structure-based acceleration techniques was broadly defined in the 1996 Advanced Accelerator Concepts (AAC) Workshop held at Lake Tahoe. The discussions encompassed all externally powered structures which are sufficiently short wavelength to be considered novel, novel material and/or novel structure design), all wake-field (excepting plasma) and other two-beam accelerators, and all inverse radiative process accelerators — inverse Cerenkov, inverse transition (vacuum), and inverse FEL. These fields have shown considerable progress since the 1994 AAC, with many more participants taking part in the discussions in the working group — more than forty in all.

Within the context of these schemes, particular emphasis was placed on experimental issues, both in the results of present experiments and in future plans. Attention was also paid to the viability of the schemes in application to linear colliders with discussions of power and particle sources (particularly for near term experimental needs), relevant aspects of transverse motion — accelerated beam quality and collective instabilities — and projected accelerator efficiency.

INVERSE RADIATIVE PROCESS ACCELERATORS

While all acceleration techniques can be rigorously viewed as inverse radiative processes, for the purpose of the working group discussion this class of accelerator was somewhat arbitrarily (but in an intuitively and aesthetically well accepted way) was limited to all far-field processes. These processes, which in practice are taken to be those employing infrared or optical radiation with conducting boundaries more than a wavelength away from the beam path, include the so-called vacuum acceleration, which is more properly termed inverse transition acceleration (ITA), the inverse Cerenkov acceleration (ICA), and the inverse free-electron laser (IFEL).

Vacuum acceleration, which is most like standard acceleration techniques in that both employ metallic structures with vacuum beam channels, was the subject of a plenary presentation by P. Sprangle[1] as well as a working group discussion led by L. Steinhauer[2]. In these schemes, the nominally transverse-polarized vacuum field pattern is focused by means of metallic or dielectric obstacles (lenses, masks or irises) to a symmetry axis or plane, yielding a longitudinal fields giving a localized acceleration. One of the main issues associated with these schemes concerns the minimization of the electric field on the obstacles, as excessive fields on these solid objects limit the acceleration gradient due to concern over breakdown. From this point of view, it should be noted that for wavelengths of far IR or shorter that dielectrics are preferable, with limits on field gradient and pulse length set by avalanche breakdown[3].

The IFEL results obtained at the Brookhaven ATF, showing MeV acceleration and excellent agreement with theory and simulation, were discussed by A. van Steenbergen[4]. Perhaps the most notable aspect of the IFEL program at BNL, however, is the proposal to use an IFEL section to pre-microbunch the beam at the 10.6 microns in order to inject into a next-generation ICA experiment. W. D. Kimura presented this proposal[5], including a summary of ICA progress to date, and emphasizing the role of coherent transition radiation diagnosis of the microbunching[6] in the planned experiments. The IFEL is also the subject of experiments in the microwave regime (MIFELA) planned at Yale[7], and the simulation results and design of this experiment were presented in the working group by R.B. Yoder. The Yale group also is investigating the ICA in the microwave limit, and an analysis of the beam dynamics for this accelerator, as well as dielectric breakdown studies in this wavelength regime were discussed by J.L. Hirshfield[8].

The microwave ICA (MICA) is not a gas-loaded device, but a dielectric-loaded wave guide with a vacuum beam hole, a pure travelling wave analogue of the common disk-loaded accelerator, which was first discussed over 45 years ago. Discovery of new, low loss materials for use at relatively short wavelengths in these devices has led to renewed interest in the MICA concept. The main problem with extending this concept to shorter wavelengths is the existence of power sources. One of the

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candidates for this source is the wake-field transformer under investigation at ANL. Computer studies of the travelling wave propagation in X-band MICA structures were presented by M. Conde.

The MICA concept originated at cm to mm wavelengths, but has been proposed, in order to take advantage of power source availability, at IR or optical wavelengths by W. Gai[9]. In this laser-excited device, one must couple radially polarized optical pulse into a travelling wave mode in a hollow optical fiber with an axicon lens. It was pointed out in discussion that this scheme suffers from excessively large wake-field problems, as well as potential Raman scattering degradation of the pump laser at "interesting" fields (1 GV/m).

Neither the IFEL nor the gas ICA are analogous to rf linacs, as they do not have paraxial particle velocity in vacuum. The IFEL, in particular, is different in that it is a second order acceleration, proportional to product of the laser and wiggler field amplitudes. A similar phenomena was reported on by J.-L. Hsu[10], who discussed the acceleration possible by ponderomotive effects in terawatt-to-petawatt laser focus. This acceleration can be considered as the inverse process of laser wake-field excitation of plasma electrons.

SLAB SYMMETRIC STRUCTURES

The luxury afforded by those who wish to accelerate particles in short wavelength structures is that the power source (*e.g.* laser) considerations are not the limiting factor in accelerating gradient optimization, as they are in microwave-based accelerators. On the other hand, very serious limitations arise due to the decreased size of the structures: geometric tolerances and power coupling become more challenging, and beam-loading and transverse wake-field effects become much more important.

It is now recognized that these limitations and challenges can be partially addressed by use of slab-symmetric structures. A precursor of the most recent ideas was discussed by H. Kirk of BNL, who discussed Smith-Purcell radiation experiments at BNL[11] and plans for related acceleration experiments. The main attraction of the inverse Smith-Purcell effect is ease of radiation coupling, as it entails use of a one-sided grating structure. However, this asymmetric system produces strongly non-uniform acceleration (as a function of distance from the grating), and a related, second order deflecting force which pushes particles away from the grating.

In order to remove the dependence of laser accelerators on peak power, as well as to symmetrize the system, a proposal for a side-injected, slab-symmetric, resonant dielectric-loaded laser accelerator[12] was presented by J. Rosenzweig. In this scheme, a dielectric-lined Fabry-Perot resonator with a small longitudinal variation (periodic at the radiation vacuum wavelength) in the input reflectivity allows a resonant standing wave accelerating field to be built up during several picosecond infrared laser illumination. This illumination can be made synchronous with the beam by used of an electro-optic sweeping technique proposed by A.A.

Mikhailichenko[13]. P. Schoessow showed 2-D time-dependent electromagnetic simulations verifying the mode patterns and filling dynamics of the structure[14].

In these slab-symmetric structures, there are several advantages obtained over cylindrically symmetric structures or open structures — there is a strong second order vertical focusing force[12,15], as well as a natural suppression of the transverse (deflecting) wake-fields *if* the beam is also very wide compared to the vertical dimensions of the structure. Analytical wake-field calculations[16] were discussed by A. Tremaine and Rosenzweig, and computational results on the problem were shown by Schoessow[14].

A scheme which is part way between the slab-symmetric resonator and the vacuum accelerator, a dielectric-loaded, slab-symmetric laser-driven accelerator operating in vacuum, was discussed by Y.C. Huang[17]. In this scheme nearby cylindrical lenses and prisms bring the laser light into a focus only in the vertical dimension. This scheme was shown to be well optimized from the point of view of media breakdown and maximum acceleration, which was estimated to be 0.5 GeV/m. Unaddressed concerns include wake-fields and a full treatment of particle dynamics.

These concepts are also under investigation in the mm-wave regime by groups at SLAC, ANL and TU-Berlin. H.Henke[18] gave a presentation covering cavity design results, 3-D computational electromagnetic modelling of structures, and fabrication techniques such as LIGA. P.J. Chou also discussed work ongoing at SLAC on fabrication and low-power testing of muffin tin structures at X-band and W-band.

An interesting result on the general question of structure coupling was presented by J. Haimson[19], who discussed a racetrack geometry which azimuthally symmetrizes the coupling cells in nominally cylindrically symmetric structures. While these results were presented for travelling wave linac sections, they are perhaps most usefully applied to standing wave rf gun designs.

EXOTIC ACCELERATORS

The attraction of the slab-symmetric systems with sheet beams is in the mitigation of short range transverse wake-field effects. Other structures have been proposed to allow damping of long-range wake-field effects. These proposals range from those already implemented in a sophisticated manner, like the damped detuned structure (DDS) at SLAC, discussed by N. Kroll and R. Jones[20], and the more exotic, like the photonic band gap accelerator (PBG). The PBG is a structure composed of many periodic (in the transverse plane) electromagnetic obstructions, with one removed at the beam hole position. This forms a defect mode which is well confined spatially, while other higher order modes are deconfined, leading to long-range transverse wake-field suppression. Recent progress on the PBG work done at UCSD was reviewed by D.R. Smith[21], and computational studies of the wake-fields studies the PBG were discussed by Derun Li[22].

The electromagnetic interaction of a charged particle with its surrounding medium — wake-field generation— is usually considered to be a linear, dissipative process. L. Schachter has proposed and analyzed cases where this is not true, when the medium is active, not reactive. In this case, particles can be directly accelerated by energy stored at the atomic level in the medium. This breaking of assumptions about energy transfer in accelerators is potentially of great importance; the usefulness of the notions proposed by Schachter await further experimental investigation.

CONCLUSIONS

The field of structure-based accelerators is going through a period of rapid growth and maturation, with some penetrating insights now being obtained from theory, computation and experiment. The level of activity is on the rise in this field, both in number of researchers and number of laboratories engaged in the work. Although in comparison to plasma accelerators, the field is still in start-up — developing concepts and technology, one can reasonably expect new and important results before the next AAC workshop.

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