CONSIDERATIONS FOR A DIELECTRIC-BASED TWO-BEAM-ACCELERATOR LINEAR COLLIDER

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Abstract

In this paper, we present a linear collider concept based on drive beam generation from an RF photoinjector, and employing dielectric structures for power extraction and acceleration. The collider is based on a modular design with each module providing 100 GeV net acceleration. A high current drive beam is produced using a low frequency RF gun (~ 1GHz), and subsequently accelerated to ~1 GeV using conventional standing wave cavities. High frequency (20 GHz) RF power, extracted from the drive beam using a low impedance dielectric structure, is used to power the main linacs, which are based on high impedance high gradient dielectric loaded accelerating structures. We envision this scheme will produce high gradients (250 MeV/m), leading to a very compact design. The modularity of the design will allow a staged construction that will enable extension to multi-TeV energies.

INTRODUCTION

Although there is ongoing effort towards the linear collider designs of ILC/CLIC [1, 2], history has shown that a good design may not be lead to a practical machine due to its cost and other factors. Technology breakthroughs should eventually lead to a compact, cheaper design. A major goal for advanced acceleration schemes is the development of a high energy physics collider [3]. Challenges for an advanced collider scheme are: high gradients (~hundreds MV/m), currently limited by material breakdown; High impedance (high R/Q), for efficiency of acceleration; and higher order mode damping, for beam breakup control. In addition, the accelerating field should have very small non-linear effects, so that positrons can be accelerated identically to electrons. Even more important, new RF power source on the order of ~ GW are required to power the structures to high gradients; that implies a new type of power generation other than klystrons is needed. One key issue for achieving high gradient seems to use short pulse RF in short structures. Another consideration for a HEP collider is the operating frequency. In general, the transverse wakefields that directly contribute to emittance growth are proportional to f^3, and the optimized frequencies are probably in the range of 10 – 100 GHz.

In this paper, we consider a two beam acceleration method using dielectrics as both power extraction and accelerating structures. Dielectric structure has shown to sustain high fields for short RF pulses and can be used as power generation devices. In general, the dielectric structure can be characterized to have: comparable impedance to metallic structures, more material choices and possible higher gradients; relatively simple geometry and thus ease of construction; and higher order mode damping is straightforward. The major difference between this scheme proposed here and CLIC is that we propose to use very short high power RF pulses (~ tens of ns and GW) generated by a high current drive beam directly produced from an RF photocathode gun. The reference design presented in this paper is for a 20.8 GHz structure.

A proof of principle experiment on dielectric structure based two beam acceleration was performed at Argonne [4] to demonstrate the concept. In the past few years, many results were obtained using dielectric devices as wakefield structures and also power extractors [5]. Here we would like point that direct wakefield acceleration in collinear structures can ultimately produce high gradients and very short pulses in dielectric structures. Due to the beam break-up control and efficiency issues in the collinear regime, it might be more difficult to realize than a two beam scheme as collider, but is worthwhile to further explore the concept.

OVERALL LAYOUT OF THE SCHEME

The proposed linear collider scheme uses a modular design. The example given here is for a 100 GeV basic accelerator module. Higher energy beams can be achieved by stacking many modules together (i.e., 30 modules for a 3 TeV machine).

A straw-man overall layout of the module is shown in Figure 1. A numerical example is given here to show the principles of the technique. All the numbers can be optimized for a particular regime or requirement. The module is made up of discrete 5 GeV sub-modules, shown in the inset of Fig. 1 and in expanded view in Fig. 3. Each sub-module consists of a 1 GeV drive beam passing through 50 stages of power extractor structures (the drive beam is generated from an RF photocathode gun and subsequently accelerated to 1 GeV by using a high efficiency standing wave accelerator with time structure as shown in Fig. 2). The 1 GeV drive beam with 50 A current will lose 20 MeV/stage, generating ~ 1 GW power, which in turn will accelerate a beam in the accelerating beamline with a 100 MeV gain. Hence, a 50-stage sub-module can be constructed with total energy gain of 5 GeV. Multiply by 20 sub-modules as shown in the Fig. 2, and a 100 GeV module can be constructed. Given the total drive beam of 1000, one could accelerate 50 small bunch trains, thus increasing the luminosity.

Figure 4 shows a standing wave linac that will be used to boost the drive beam energy. In order to efficiently deliver rf power to the beam, a few preferences need to be considered in the design: 1) low rf reflection; 2) low wall losses of the structure; 3) high beam loading. An L-band high coupling coefficient (β=10) structure has been studied numerically. Using 1.3 GHz as a reference frequency for drive beam acceleration, with the drive beam structure in Fig. 2, 76% of the rf power can be delivered to the beam, and average energy gain is 2.3 MeV/m for 30 MW.

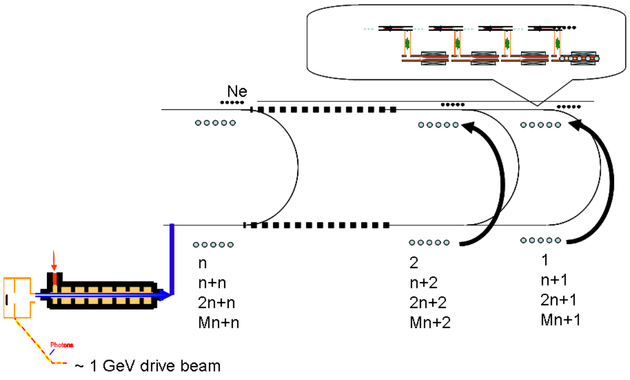

Figure 1: Layout of the 100 GeV accelerator module.

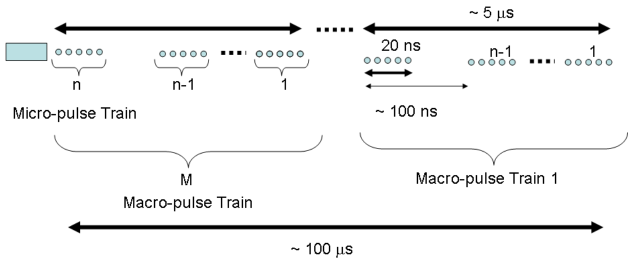

Figure 2: Time structure of the drive beam. For high efficiency beam acceleration: 1 GeV, 50 A. A long RF pulse (100 micro-second) generate a pulse train of 10 – 20 ns, spaced at 80 nano-second. One reason for this parameter choice is that 30 MW and 100 µs L-band klystrons are within reach of commercially available products.

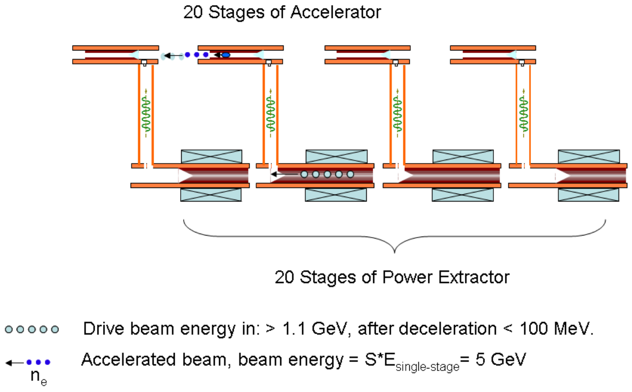

Figure 3: Acceleration module per drive beam: power extraction, 50 stages, 1 Gw each stage. Accelerator consists of 50 stages, each stage accelerating the beam by 100 MeV.

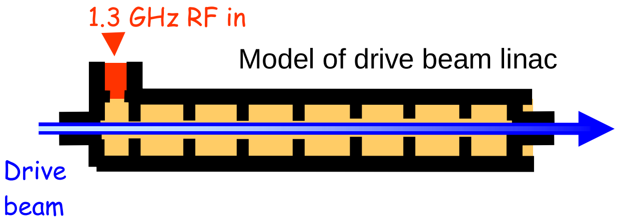

Figure 4: A standing wave accelerator for high efficiency drive beam acceleration.

ACCELERATING AND POWER EXTRACTION STRUCTURE PARAMETERS

RF breakdown physics is complicated and yet to be fully understood. However, the existing data [5, 6] point to higher RF breakdown threshold (or lower breakdown rate) with shorter pulses (~ 10 ns). Therefore, the most likely chance of achieving much higher gradient than the existing 100 MV/m state of art would be a structure powered by a short RF pulses. With higher gradient and lower breakdown rate, this may give us a path to high gradients for multi-TeV class accelerators using short pulse train generated wakefield acceleration: one can generate RF with high current electron beams; RF pulse length can be easily controlled.

Examples of a power extraction device and accelerating structure are given in Tables 1 and 2. For the power extraction device, several modest high power extraction experiments at the AWA have been performed in the past several years, with power of 40 MW achieved [7]. Certainly, high band width, high power and low fields can be obtained in this structure using quartz material as the dielectric.

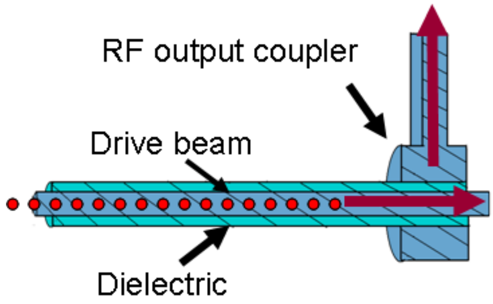

Figure 5: Schematic of a dielectric power extractor. High rf power is generated from a pulsed electron beam train passing through the structure.

Table 1: Parameters for Power Extraction Device

f - GHz	20.8
σz - mm	1.5
Er	3.75
a – mm	4
b – mm	5.86
L – m	0.37
Vg/c	0.34

P – GW	1.03
Gaverage	53.0
Gmax (at exit) – MV/m	108

Table 2: Parameters for the Accelerator

f – GHz	20.8
Er	12
a – mm	2
b – mm	3.5
L – m	0.40
Vg/c	0.08
P – GW	1.03
Fill time (ns)	~ 10.0
Ez – MV/m	250

A perceived advantage of the short pulse powered structure is that it requires high bandwidth. The dielectric tube by nature is a broadband device, and thus only a broadband coupler is required. Although this requirement may present a challenge in the design, once designed, the machining tolerance can be rather loose, thus reducing cost of construction, particularly in mass production.

R&D ISSUES WITH THE SCHEME

So far, we have performed qualitative parameter studies for a scheme based on the dielectric two beam acceleration concept. The scheme seems to be reasonable if a few critical assumptions can be proved, such as: Drive beam generation and acceleration; GW RF generation and high gradient demonstration in structures.

We would like to emphasize that the proposed scheme does not strictly depend on whether the dielectric structure concept works or not, but any structure that can sustain high gradients under short pulses can also be used. Any low cost structures may also be a critical issue for future collider designs.

Currently, we are upgrading the AWA facility that will enable us to demonstrate the critical technologies [8]. We have constructed a RF photocathode gun with CsTe cathode, and it will generate exactly the pulse structure as required, and with additional linac tanks we will be able to increase the beam energy to 75 MeV and with average current of 50 to 100 A and pulse length of 10 – 20 ns. With this drive beam, one should be able to generate ~ GW level RF to test structures at the 500 MV/m level, thus providing the basis for the proposed linear collider scheme.

SUMMARY

We have described a modular scheme that uses a two-beam acceleration method with dielectric loaded structures as both power generating and accelerating devices. The scheme is compact and straightforward. However, there are still challenging issues to be resolved, such as high gradient demonstrations, short pulse high power RF generation and high current electron beam propagation.

ACKNOLWLEDGEMENT

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