The CERN Study of a 2 TeV e^+e^- Collider CLIC

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Abstract

Progress with the CERN study of a 2 TeV e^+e^- linear collider (CLIC) is reported. The CLIC Test Facility for drive beam generation is giving first results. Results are also reported from development work on 30 GHz prototype accelerating structures (including RF quadrupole configurations) from a 30 GHz "transfer structure" for RF power generation in the CLIC two-beam scheme, from a prototype system for submicron automatic alignment and from theoretical work on wake-field stabilization, alignment tolerances, compensation of the beam's energy spread and the final focus system.

INTRODUCTION

Research and development on a 2 TeV centre-of-mass linear collider continue at CERN. The tentative parameters towards which the work is directed have changed little over the last few years; an updated list is given in another contribution to this conference [1]. Our design is based on a two-beam scheme. The 30 GHz main linacs (80 MeV/m, 1.7 kHz repetition rate) will be powered by tightly bunched drive beams in the GeV range via low-impedance travelling-wave transfer structures. The drive beam will receive its energy from superconducting CW cavities in the UHV range (350 MHz).

More detailed reports, covering most of the ongoing work, are contained in companion papers [1] to [7]. Exceptions to this are the injector complex [8] [9] and a test facility for drive-beam generation under construction [10]. This paper gives a general overview.

ACCELERATING STRUCTURES AND ALIGNMENT

The main linacs will be built from 30 cm long, iris-loaded travelling-wave sections containing 80 cells and a coupler (to WR 28 waveguide) at each end. The aperture diameter is 4 mm, the cell diameter 8.7 mm, the group velocity 8.2% c. The outer diameter of the structure (35 mm), machined to ±1 μm precision and concentricity with the beam aperture, serves as the reference for alignment. The cells are pumped through four radial holes via brazed-on manifolds. Parallel channels for water cooling are drilled into the copper. Each cell can be deformation-tuned by forming a pair of diametrically opposite dimples.

Fabrication is by brazing from precision-machined cups. A special feature is an annular copper to copper diffusion bond around the cell boundary (and also at the outer diameter) preventing any risk of wetting the cavity surface by excess braze. Further details of this development - which is well advanced by now - are given in ref. [11]. After the finishing of a 30-cell prototype a first full-length 80-cell structure has been built. It is shown in Fig. 1.

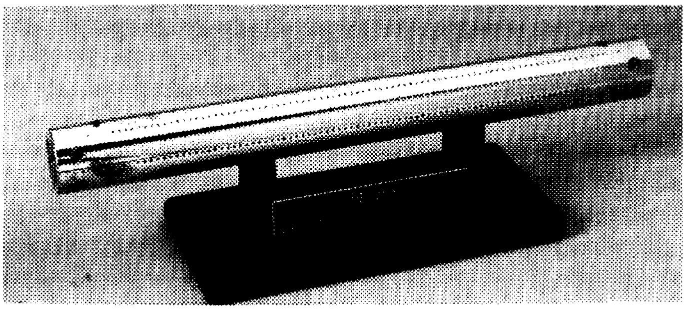

Figure 1. Prototype 30 GHz accelerating structure

It is part of our plans to employ microwave quadrupoles for wake-field stabilization. Such quadrupoles - featuring simultaneous acceleration and time-dependent transverse focusing - can be obtained by giving a fraction of the accelerating structures a rectangular aperture in a circular cell or a circular aperture in a flat (*quasi* rectangular) cell. The latter is much to be preferred since it permits machining of the aperture, including the required edge radius, on a precision lathe. Precision-machined prototype discs of this kind are shown in Fig. 2. The fabrication technique is identical to that for the normal accelerating structure except that the cavities are milled. Details are given elsewhere at this conference [2].

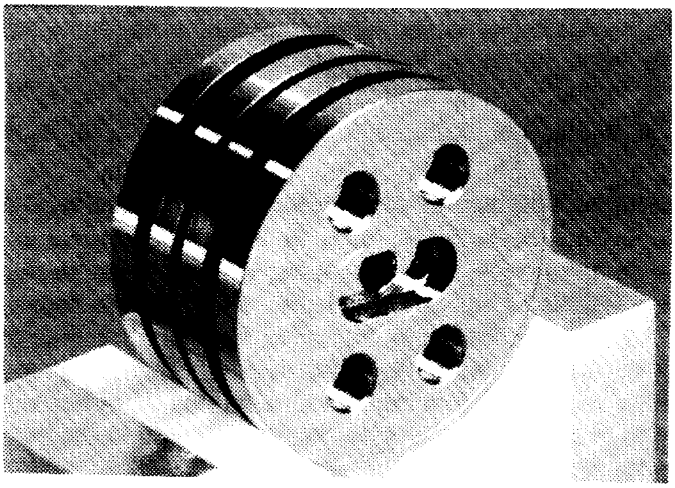

Figure 2. Microwave quadrupole cell; flat cavity, circular aperture of 4 mm diameter. These cells will be assembled to form a structure exactly like that of Figure 1.

Since the tolerances on transverse misalignment and jitter are particularly tight in our design - of the order of 1 μm for

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quadrupoles in fact - this problem has been made the subject of special hardware developments.

On the one hand it is envisaged that the beam position will be measured to sub-micron resolution by means of simple E_{110} cylindrical cavities fabricated integrally with the accelerating structures and quadrupoles. The cavity frequency has been chosen as 33 GHz, 3 GHz above that of the main linac frequency, in order to avoid interference from the RF power pulse. To obtain the maximum resolution, narrow band detection of the cavity output is required and a heterodyne approach has been adopted. Information on the sign of the beam's displacement will be obtained using the RF power pulse as reference and, due to the 3 GHz offset, a relatively complex receiver results, with three pairs of intermediate frequencies [12]. Prototype development is well under way

On the other hand, an active alignment test facility [13] - permitting controlled submicron displacements - has been built in an unused underground tunnel at CERN. Figure 3 shows part of the latest status of this remote computer-controlled facility, described in more detail in another contribution to this conference [3].

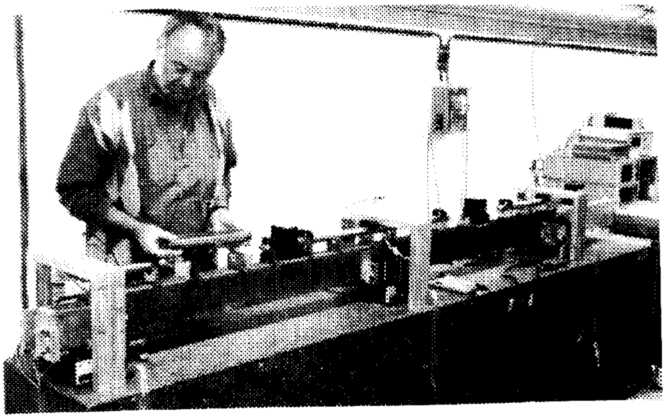

Figure 3. Active alignment facility with submicron reproducibility

DRIVE LINAC AND POWER TRANSFER

The multibunch high-intensity drive beam of a few (3 to 5) GeV energy runs parallel to the main beam at about 1 m distance. The drive beam delivers energy to 30 GHz travelling-wave transfer structures which thus form the pulsed RF power sources of the main linac sections to which they are connected by rectangular waveguides. The drive beam is periodically reaccelerated by strings of superconducting cavities placed at a few hundred metres' distance at least. Present-day storage-ring cavities - operated CW at low UHF frequencies and powered from CW klystrons in the megawatt range - are quite suitable for this purpose. Our tentative design is based on the cavities developed for LEP 200 (about 5 MV/m at 350 MHz).

Very high bunch charges are required in the drive beam in order to satisfy the energy balance [14] of the system so as to keep approximately constant drive beam energy. It is a welcome corollary that the impedance of the transfer structure must be very low. A promising design [4], [5] - which is being studied by a combination of scale models and computation - consists of a circular cylindrical beam tube of relatively large diameter (15 mm) which is coupled to the broadside of a rectangular output waveguide through a row of coupling holes. Output waveguide cutoff and coupling hole spacing are chosen to be such that the beam is synchronous with the backward TE_{10} wave of the output waveguide at 30 GHz. The RF pulse length is controlled by the length of the coupling sections. By placing output waveguides on both sides of the beam tube, 160 MW/m can be extracted with sections lengths of 50 cm. Figure 4 shows a scaled-up (9 GHz) low-power model.

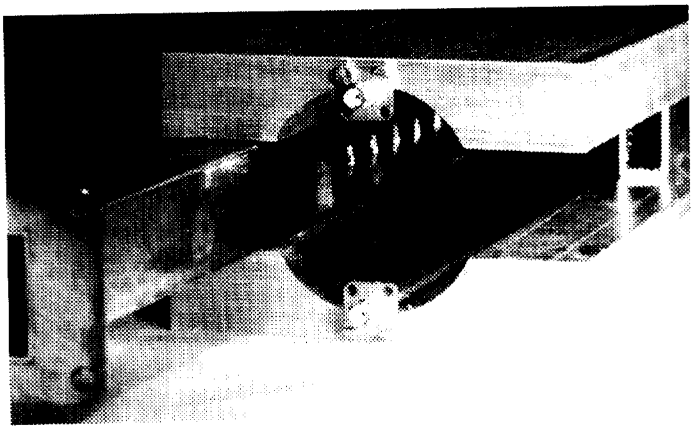

Figure 4. Scale model (9 GHz) of the transfer structure. One output waveguide (WR 90) with its coupling holes is visible to the right. The coaxial plugs on top and bottom connect to TEM lines simulating the beam. Frequency response from these lines to the waveguide output is measured, then folded with the bunch spectrum foreseen for CLIC and Fourier transformed to give the RF envelope in the time domain.

DRIVE BEAM GENERATION AND TEST FACILITY

The generation of a drive beam, consisting of bunches of 1 mm r.m.s. length, 1 cm spacing and 10^{12} particles requires development. It is proposed that trains of such bunches, separated by the drive linac wavelength of c/350 MHz , will be generated by a battery of complex pre-accelerators. In order to study the feasibility of these devices, an experimental CLIC test facility (CTF) is in preparation [10]. It includes an RF gun, a beam line acting as magnetic spectrometer, acceleration to ~ 60 MeV and RF power generation at 30 GHz. A pulse compressor may be added eventually.

A key element of this facility is the laser-driven photocathode and a d.c. test bench has been built for testing its fabrication [15]. Best results so far (7×10^{11} e^- in a space-charge limited current of 12 A and a quantum efficiency of 2.5%) have been achieved with Cs_3S_b and 266 nm laser wavelength, and a quantum efficiency of 3% was achieved with a CsI cathode at 213 nm wavelength.

The aim of the CTF itself is to study generation of very short (picosecond) high intensity bunches and to produce

30 GHz RF power by deceleration in a transfer structure. Using a CLIC accelerating structure instead of the low-impedance transfer structure described above sufficient power may be created [16] to drive a second CLIC structure to its nominal gradient of 80 MV/m. The test facility is still under construction but a provisional test of its RF gun has demonstrated the capability of 80 MV/m at a CsI cathode and a few amperes' peak electron current.

WAKE FIELD DAMPING

Beam stability along the main linac in the presence of wake fields has been studied extensively [6] in conjunction with a minimization of the energy spread [1]. The loss factors and frequencies have been computed for more than 200 modes of the wake fields, and the optical model correction added. The required focusing system is made of a FODO lattice with quadrupoles arranged with alternating gradients at suitable period lengths scaled with the square root of energy. Both conventional and microwave quadrupoles were assumed for controlling beam break-up by variation of transverse focusing strength along the bunch.

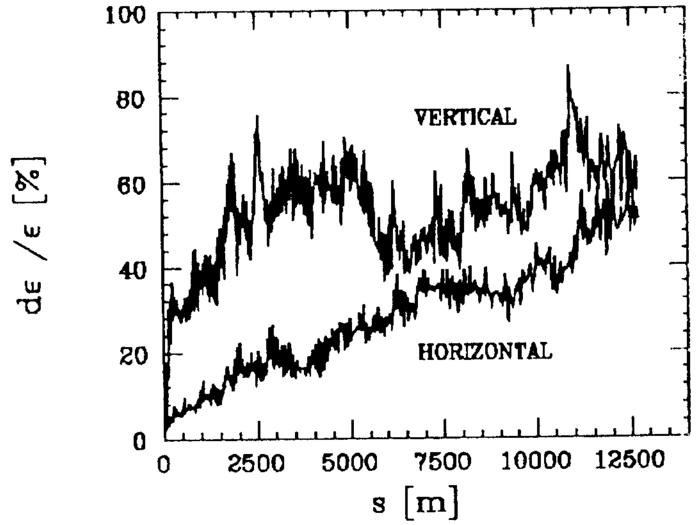

Figure 5. Emittance blow-up for alignment scatters of 1 μm and 5 μm r.m.s. for quadrupoles and accelerating structures respectively.

Tolerances on misalignments of quadrupoles and accelerating sections made it necessary to investigate different trajectory correction schemes, such as a one-to-one correction centring the beam at each monitor, or a dispersion-free algorithm [17]. Wake-field damping with the linear gradient of transverse focusing [18] and with autophasing [19] (which includes the nonlinearity of the field) was studied in detail, as well as the associated question of strong emittance beating that may appear. A division of the linac into four sectors was introduced to optimize autophasing with conventional quadrupoles only and negative RF phases. However, the addition of microwave quadrupoles [2] allows the use of positive RF phases and produces provisional results at 1 TeV compromising between emittance blow-up (Fig. 5) and energy spread (< 0.6% r.m.s.), with misalignment tolerances of the order of 1 to 5 μm.

FINAL FOCUS

Compensation of the energy spread using the wake potential versus the RF sine wave has been shown to be possible in the main linac by adjusting the bunch length and the phase of the accelerating voltage for a given charge per bunch. The optimum retained corresponds to a bunch length of 0.17 mm, a phase of 7-8° and $6 \cdot 10^9$ particles per bunch. This gives an r.m.s. energy spread of about 0.1% in a perfect machine and leaves tails with about 15% of particles that do not contribute to the luminosity, being outside the final focus acceptance. The concomitant luminosity was calculated in the presence of aberrations and synchrotron radiation in the final focus system and including pinch effect [7]. For two bunches colliding head-on (and after adjustment of the beta-values at the crossing point), the blow-up of the beam size could be kept small enough to exceed a luminosity of $10^{33}\text{cm}^{-2}\text{s}^{-1}$, taking into account an enhancement factor larger than 2. (Effects of small crossing angle and off-sets due to errors in quadrupole positioning are being estimated.)

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