OVERVIEW OF THE CLIC BEAM INSTRUMENTATION

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Abstract

The performance of the Compact Linear Collider (CLIC) will rely on extremely tight tolerances on most beam parameters. The requirements for the CLIC beam instrumentation have been reviewed and studied in detail for the whole accelerator complex. In the context of the completion of the CLIC Conceptual Design Report, a first attempt was made to propose a technical solution for every CLIC instrument. Even if these choices are based on the most recent technological achievements, whenever possible, alternatives solutions focusing on potential improvements in performance, reliability or cost minimization are proposed for further study in the future. This paper presents an overview of the CLIC beam instruments, gives a status of their already achieved performances and presents the future work activities.

INTRODUCTION

The next generation of electron-positron colliders aims at producing high collision rates at a center of mass energy 0.5TeV or higher [1]. At CERN, the Compact Linear Collider (CLIC) study [2] uses normal conducting accelerating cavities operated at a high gradient of 100MV/m and powered by 12GHz high-power RF pulses. Since conventional RF sources cannot provide such pulses, the CLIC scheme relies upon the so-called two-beam-acceleration concept, where a high-current electron beam, the Drive Beam, runs parallel to the main beam and is decelerated to generate the RF power. The actual CLIC RF source design, proposed in the late 1990s, is based on an innovative Drive Beam Accelerator complex [3]. This relies on an elegant way of combining and transforming long, low-frequency RF pulses into short, high-power pulses at high frequency. A general layout of the CLIC complex at 3TeV is depicted in Figure 1.

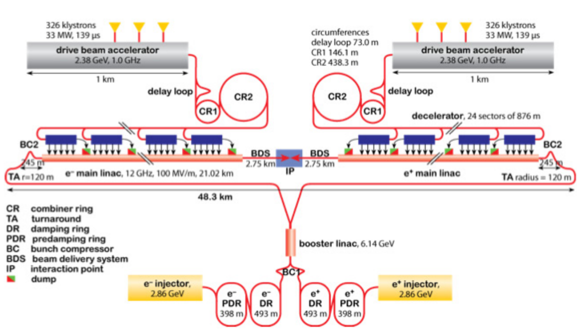

Figure 1: CLIC layout for 3TeV centre of mass energy.

Achieving high luminosity requires colliding beams with nanometer spot size and short bunch length [4] and this puts a high demand on the performance of most of the beam instrumentation systems. The extremely small emittance beams are generated in the Pre-Damping and Damping Rings. These emittances must be conserved over more than 40km, first through long transfer lines and then all along the main linac, which requires a precise control of the beam position. The bunch length is shortened from 2ps down to 150fs sigma in two consecutive stages, the last compression stage being located just before the main linac. At the interaction point, the beam is finally focused to only a few nanometers in size. After the collision highly disrupted beams need to be dumped in clean conditions, making sure that the 14 megawatts of power carried by the particles are safely absorbed.

The Drive Beam complex produces a series of 2.4GeV electron beams with high current (100 A) and high bunch frequency (12 GHz) using a bunch frequency multiplication scheme where bunched beams are interleaved by means of transverse RF deflectors [5]. These drive beams are then distributed all along the CLIC main beam accelerator to produce the required 12GHz RF power locally, being decelerated over several hundreds of meters to an energy of 250MeV.

This paper gives an overview of the CLIC beam instrumentation needs. It describes the technology choice for the most challenging instruments and presents the plans for the future developments. Some specific Drive Beam instruments are not discussed in this paper but information on monitors for high energy-spread beams in the decelerator and for optimising bunch frequency multiplication are presented in [6] and [7]. The current design of the CLIC luminosity monitors can be found in [8].

OVERVIEW

The number of instruments foreseen for the Drive and the Main beams are reported in Tables 1 and 2 respectively.

Table 1: Number of Beam Instruments in the Drive Beam

Instruments	DB surface	DB Tunnel	DB Total
Intensity	38	240	278
Position	1834	44220	46054
Beam Size	32	768	800
Energy	18	192	210
Energy Spread	18	192	210
Bunch Length	24	288	312
Beam Loss /Halo	1730	44220	45950

Table 2: Number of Beam Instruments for the Main Beam

Instruments	MB surface	MB Tunnel	MB Total
Intensity	86	98	184
Position	1539	5648	7187
Beam Size	34	114	148
Energy	19	54	73
Energy Spread	19	4	23
Bunch Length	17	58	75
Beam Loss /Halo	1936	5854	7790
Beam Polarization	11	6	17
Tune	4	0	4
Luminosity		2	2

BEAM POSITION MONITORING

The beam position monitor (BPM) system for CLIC is extensive; the complex for the luminosity beams contains about 7200 BPMs while that for the drive beams requires about 46000. There is a wide variety of different types of BPM with differing beam pipe apertures and performance requirements.

The main beam linac requires one BPM per quadrupole, a total of 4196 BPMs, with 50nm resolution. Single-bunch spatial resolution better than these requirements has already been demonstrated using cavity BPMs [9]. Even if this is not expected to be a major problem, the required temporal resolution implies a BPM design with a bandwidth of 20MHz, much broader than that existing in current systems [10,11].

The proposal for the main beam linac BPM consists of two cavities [12] as depicted in Figure 2(a). The position cavity supports degenerate X and Y dipole modes at 14 GHz, with the signals brought out on four dipole-mode selective couplers, two for each of the X and Y position signals. The reference cavity, with a monopole mode frequency also at 14 GHz, provides the beam charge and phase signal used to normalize the position signals.

Three CLIC cavity BPMs are currently under fabrication and will be tested in 2012. Wakefield simulations have been initiated and an alternative BPM design based on a choke-mode cavity will be launched if the wakefield simulations show a risk of degrading the beam quality with the current BPM design.

(a)

(b)

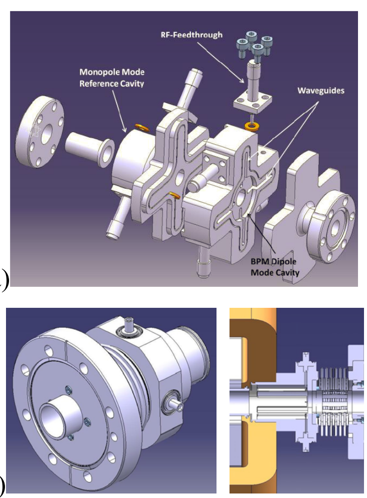

Figure 2: (a) Main Beam Linac Cavity BPM (b) 3D model of a Drive Beam Decelerator BPM and its integration in the CLIC module.

The specifications for the drive beam BPMs represent a unique combination of issues: they need to be produced in very large quantity (75% of all CLIC BPMs); they need to measure in the vicinity of an RF structure producing more than 100 MW of RF power at 12 GHz; they need to have a temporal resolution of 10 ns in order to provide a position signal along the bunch train. In addition, the required accuracy of 20 microns and resolution of 2 microns in a beam-pipe aperture of 23 mm, imply very accurate calibration and.

The proposed, cost effective solution is based on short stripline BPMs of 25mm length, with position signals processed at baseband in a bandwidth of 4 – 20 MHz. The striplines are proposed to be built into the quadrupole vacuum chamber as shown in Figure 2(b). Prototypes are being manufactured and will be tested on CTF3 to be compared with the inductive pick-ups [13] currently used in the machine.

BEAM PROFILE MEASUREMENT

With the total number of required devices exceeding 1000, transverse and longitudinal profile measurements becomes a very large system, 3 times larger than the current number of such devices actually in use at CERN. Whilst the Drive and the Main beams have very different parameters, their charge densities can reach levels well beyond the damage threshold of any physically interceptive monitor. For this reason the choice of instrument technology has favored non-intercepting devices wherever possible. However, in most cases, more than one detector technology needs to be foreseen to cover all the operational needs.

Transverse Profile Monitors

Spatial resolution higher than 20microns, as requested in the Main Beam injector and in the Drive Beam complex, can be easily achieved using Optical Transition Radiation screens [14]. However, beam induced thermal loads will limit the use of such devices for beam sizes smaller than 500um for the MB and 3mm for the DB. This implies working with a reduced beam charge or pulse length, or using non-interceptive devices for high charge beams.

The beam emittance is significantly reduced in the damping rings and requires monitoring with a 1micron resolution. In the CLIC complex, this concerns more than 80km of beam line and a total of more than 100 devices. In the rings and turn-arounds, imaging systems based on synchrotron radiation are being developed in the X-ray regime [15] [16] to push this spatial resolution to the micron range. In parallel, an innovative technique has been successfully tested in PSI [17] based on the measurement of the Point Spread Function (PSF) of an imaging system. In the linacs, electron beams with sizes of a few microns, have been measured at the ATF extraction line [18] using a Laser Wire Scanner (LWS) as shown in Figure 3. Ongoing R&D at ATF2 is concentrated on understanding the systematic effects and on pushing the measurement scale down to one micron or less. Developments at PETRA3 [19] are addressing the possibility to operate a LWS as a turn-key system. R&D on the laser systems themselves [20] is also crucial and centred on developing fibre lasers because of their many attractive properties. A fibre laser output should be nearly perfectly Gaussian at any level of amplification, and should operate with high efficiency (absorbed pump power to laser output efficiency of 85%). LWS are also envisaged as non-intercepting transverse profile monitors for the Drive Beam wherever necessary. However, they remain expensive and complicated devices and a cheaper easier alternative monitor based on Diffraction Radiation (DR) is currently also being investigated. Such systems, operating in the visible range, have been tested on several accelerators [21,22,23]. The achieved resolution on the beam size was at best 13μm. To reach a resolution better than 10 μm, a possible upgrade would use DR in extreme UV or X-ray spectral-range. An experimental validation of such a scheme is proposed during the coming years on the CESR-TA ring at Cornell/USA.

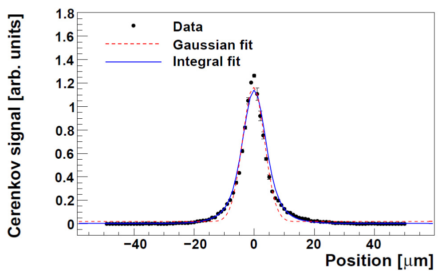

Figure 3: Vertical laser-wire scans in the ATF

Longitudinal Profile Monitors

The most stringent requirements for bunch profile measurement occur at bunch compressor BC2, where the longitudinal profile of a high charge density, 44μm (150fs) rms length bunch, needs to be measured with a resolution of 6μm (20fs) rms. For locations where only information on the rms bunch length is needed, monitors based on Coherent Diffraction Radiation (CDR) [24] can be used. However, before and after bunch compression, a full knowledge of the bunch profile is desired and the measurement must be totally non-intercepting. The use of a Temporal Decoding (TD) electro-optical method [25] is therefore under consideration to measure these short bunch profiles. In experiments undertaken at FLASH, single-shot TD has been demonstrated with time resolution of 120fs FWHM (~60fs rms) [26]. For CLIC prototypes, R&D will also need to address operational reliability as well as the more challenging task of achieving the higher time resolution. Providing a sufficient detection bandwidth implies an improved encoding scheme using alternative EO materials and multiple-crystal detectors. Faster temporal decoding systems relying on Frequency Resolved Optical Gating (FROG) are also under consideration.

BEAM LOSS MONITORING

As an integral part of the CLIC machine protection system [27], the CLIC Beam Loss Monitoring (BLM) system [28] should detect potentially dangerous beam losses and prevent subsequent injection into the main beam linac and the drive beam decelerators. The system should also assist in beam diagnostics, localizing and characterizing the beam loss distribution. This includes the ability to measure the time structure of the loss, which can indicate the origin of beam perturbations.

The CLIC BLM system requires a very large number of devices. Compared to other existing large BLM systems [29], one challenge of the CLIC BLM system is the requirement to identify structure specific beam losses along the CLIC modules where both beams propagate simultaneously and in parallel. At this stage the proposed detector uses standard and robust ionization chambers but an innovative technique based on Cherenkov optical fibres is under investigation [30].

SUMMARY

The needs for beam diagnostics in the CLIC complex have been globally reviewed and technological solutions proposed for every instrument. These choices will serve as a baseline for the next phase of the project, concentrating on the engineering and the test of CLIC prototypes.

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