WAKEFIELD MONITOR DEVELOPMENT FOR CLIC ACCELERATING STRUCTURE

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Abstract

To achieve high luminosity in CLIC, the accelerating structures must be aligned to an accuracy of 5 µm with respect to the beam trajectory. Position detectors called Wakefield Monitors (WFM) are integrated to the structure for a beam based alignment. This paper describes the requirements of such monitors. Detailed RF design and electromagnetic simulations of the WFM itself are presented. In particular, time domain computations are performed and an evaluation of the resolution is done for two higher order modes at 18 and 24 GHz. The mechanical design of a prototype accelerating structure with WFM is also presented as well as the fabrication status of three complete structures. The objective is to implement two of them in CTF3 at CERN for a feasibility demonstration with beam and high power rf.

INTRODUCTION

The alignment of the accelerating structures in the CLIC main linac is necessary to remove the wakefield effects on the beam. Simulations showed that the emittance growth can be very well improved by aligning the accelerating structures to an accuracy of 5 µm [1]. The full specifications are presented in Table 1 for the commissioning and operation of CLIC in comparison with the CTF3 test conditions.

Table 1: Wakefield Monitor Specifications

Parameters	CLIC commissioning	CLIC operation	CTF3
Charge / bunch (nC)	0.06	0.6	0.6
Number of bunches	1-312	312	1-226
Bunch length (µm)	45-70	45-70	400
Train length (ns)	156	156	150
Bunch Spacing (ns)	0.5	0.5	0.66
Accuracy (µm)	5	5	
Resolution (µm)	5	< 5	
Range (mm)	± 2	± 0.1	± 2
Beam Aperture (mm)	~5.5	~5.5	~5.5

To achieve such accuracy in operation, the beam based alignment is foreseen. It consists of using the transverse higher order modes generated by an offset beam in the accelerating structure in order to evaluate and correct the misalignment. This method has been explored on X-band structures at SLAC [2], at S-band in CTF2 [3] and on superconductive L-band cavities at DESY [4]. The challenge is to adapt and test this technique on the current CLIC accelerating structure and demonstrate its feasibility.

WAKEFIELD MONITOR RF DESIGN

The basic design of the CLIC accelerating structures consists of 24 tapered and weakly coupled cells working on the $2\pi/3$ mode at 12 GHz, with a mean aperture of 5.5 mm. Each cell has four orthogonal waveguides and rf absorbers in order to damp strongly the higher order modes (HOM) induced by the beam [5]. The dipole modes, usually used for the offset detection are above 16 GHz with a Q factor below 10, making the signal processing particularly challenging. Also, since no length is available in the main linac, the WFM has to be integrated to the structure, without modifying its accelerating and damping properties. The WFM must finally deal with the proximity of high peak power rf signals, which is not the case in a cavity BPM.

The rf design of the 12 GHz prototype structure with WFM is presented in Fig. 1.

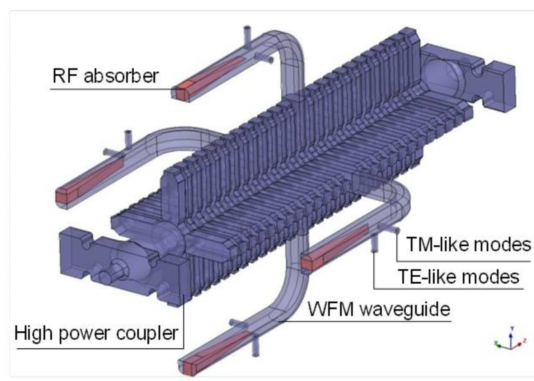

Figure 1: 12 GHz prototype accelerating structure with wakefield monitor (vacuum volume).

The wakefield monitor consists of a bent waveguide extending the damping waveguide with the same section. There are four waveguides per structure which are 90° bent for size reasons and connected to the middle cell to have the mean offset of the structure. Two coaxial rf pick-ups are implemented on the WFM waveguide: one on the large side to extract the TM-like modes and the other one on the small side to extract the TE-like modes. The TM-like and TE-like modes are hybrid electromagnetic (HEM) dipole modes in the cavity. They are coupled to the damping waveguides and propagate with the TE_{10} mode in the bent waveguide on respectively the vertical (cut-off frequency Fc=13.3 GHz) and horizontal (Fc = 21.2 GHz) polarization. The internal conductor of the pick-up is inserted 1 mm inside the waveguide giving a coupling factor of -10 dB while keeping the reflection level to the cell below -20 dB. In a first step, the structure does not include the SiC absorbers, except for the middle cell where the WFM is implemented.

TM-like Modes

The TM-like modes excited by an offset beam have been computed in time domain using the parallel code GdfidL [6] (Fig.2). A single bunch with a longitudinal beam size of $\sigma_z = 3$ mm and a charge of 0.6 nC have been used. In order to remove all monopole components in the signal, a 180° perfect recombination is done between the two diametrically opposite ports.

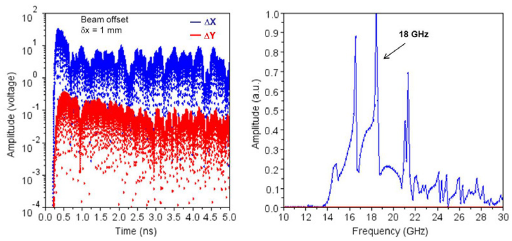

Figure 2: Horizontal (blue) and vertical (red) port signal amplitude of the TM-like modes after 180° recombination in time (left) and frequency (right) domain for a beam offset of 1 mm on the horizontal plane.

In time domain, the horizontal recombined signal (blue curve) is a factor of 100 higher than the vertical one (red curve). This means that the intrinsic resolution is about 10 µm, assuming a perfect geometry of the structure, a hybrid coupler with infinite isolation and no thermal noise. On the frequency spectrum, one can see that the 12 GHz fundamental mode is well rejected and that the lowest dipole-band mode around 18 GHz is predominant. The resolution will be very well dependant to the 180° hybrid coupler which has a typical isolation of 15 dB.

TE-like Modes

For the TE-like modes, no recombination is needed since the rejection of the fundamental mode is very good.

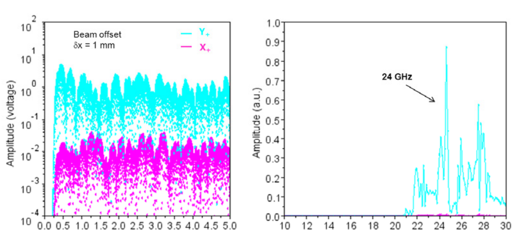

Figure 3: Horizontal (cyan) and vertical (magenta) port signal amplitude of the TE-like modes in time (left) and frequency (right) domain for a beam offset of 1 mm on the horizontal plane.

The simulated signals shown on Fig. 3 illustrate that the difference in amplitude between the vertical (magenta curve) and the horizontal (cyan curve) signals is a factor of 100 to 250. Assuming a perfect geometry of the cells and no thermal noise, a theoretical resolution of 4 µm may be achieved. The involved modes have resonant frequencies going from 22 to 28 GHz, with a significant amount of signal at 24 GHz.

Linearity, Power Range and Time Resolution

The linear variation of the voltage signals at the ports has been checked by running GdfidL with different beam offsets going from -1 to +1 mm. The phase of the signals must be measured in order to know the sign of the offset.

To estimate the power of the ports signals, the longitudinal beam size have been varied in GdfidL from $\sigma_z = 4$ to 2 mm and extrapolated to 45 µm using the electric form factor defined in [7]. For the TM modes, the peak power goes from 10 µW (for 5 µm offset, 0.06 nC and $\sigma_z = 4$ mm) to 1 kW (for 2 mm offset, 0.6 nC and $\sigma_z = 45$ µm). For the TE modes, the power level is approximately ten times lower.

With a single bunch excitation, Fig. 2 shows that the TM signal decreases quickly with a Q of around 10 during the first 1 ns and stays constant after, due to the fact that in our case, SiC loads are replaced by short circuits in the other cells. It means that few accumulation of signal will occur in multi-bunch operation (and even fewer with rf absorbers everywhere) and that the time resolution of the acquisition system must be better than about 0.05 ns to detect the signal envelop. For the TE signal, the first 1 ns decrease is slower with a Q of around 60.

MECHANICAL DESIGN

Accelerating Structure

The fabrication technology of the accelerating structure follows the baseline manufacturing flow defined by the CERN-SLAC-KEK collaboration to achieve a gradient at 100 MV/m range [8].

The accelerating structure is 338 mm long and its weight is about 22 kg. The structure consists of 24 so-called "regular" disks and 3 disks specially designed for the connection of the WFM waveguides (see Fig. 4).

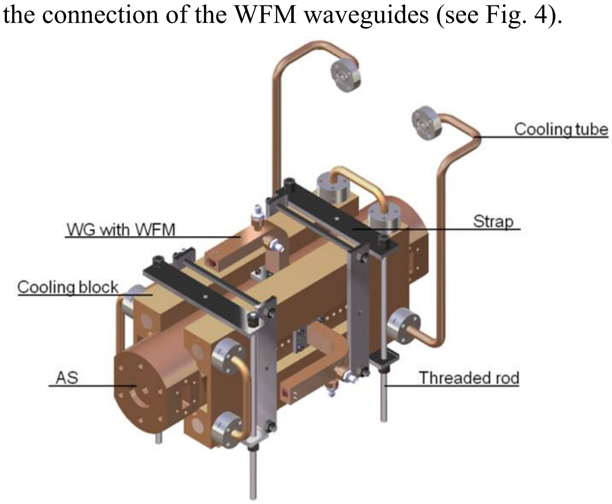

Figure 4: Layout of accelerating structure with WFM.

The diffusion bonding process in a dry hydrogen environment at about 1000°C is used to join the disks stack. The reference surfaces for the disks and couplers assembly are the external diameter Ø80±0.002 mm and the butt ends of each disk with a flatness of 0.001 mm.

A first bonding phase is done separately on the high power couplers followed by a cleaning procedure and a re-machining in order to have a flat surface for the high power waveguide connection. This helps to make sure that all mechanical residuals are removed. The disks stack and the prepared couplers are then bonded together.

The assembly procedure is completed by adding the cooling blocks, tubes and WFM waveguides. The water cooling is adopted for the heat evacuation from the structure. The external cooling circuits consist of two cooling blocks, which are clamped on the AS body by means of straps and threaded rods. An accomplished study shows that such a cooling circuit gives a nearly uniform temperature distribution along the structure.

The rf tuning system integrated to each cell is based on the push-pull principle. It is possible to increase or decrease the internal volume by deforming the thin wall. To maintain the cavity symmetry, there are four tuning studs per cell.

WFM Waveguides

The WFM waveguides are made of two halves precisely machined and brazed together using the AgCuPd brazing alloy (see Fig. 5). The next step is the machining of the waveguide end and the brazing with a flange (connection plate) equipped with two precise holes, necessary for guiding pins.

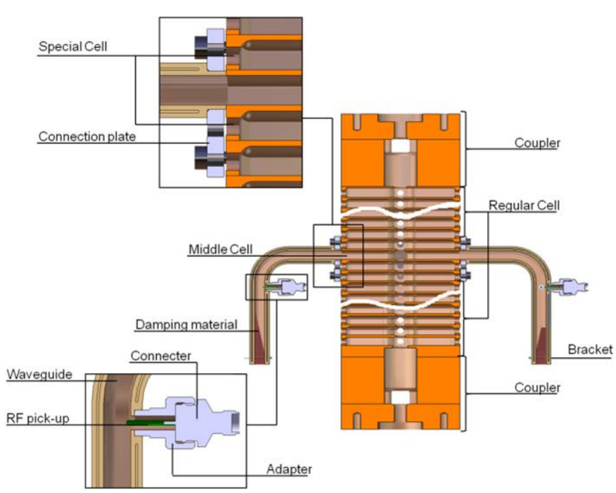

Figure 5: Longitudinal cut of the accelerating structure.

A good electrical contact is provided by tightening of four bolts, used for fixing the waveguide on the structure body. The SiC absorber is fixed in each WFM waveguide by means of bracket. The coaxial connectors with the screwed antenna are fixed directly to the adapter. The TM like mode RF pick-up is placed slightly differently on the bottom WFM waveguide. This is mainly due to limited space, necessary to bend the cable coming out.

FABRICATION STATUS

After a pre-machining at 0.1 mm and a annealing at 240°C during 4 hours, the surface is formed by milling and turning operations with monocrystal diamond tools. The final machining installation has a programming resolution of 1 nm and is equipped with linear motors and air bearing slides. A tolerance of 2.5 µm, a surface roughness of 25 nm and flatness better than 2 µm have been demonstrated on five prototype disks. Three complete structures have been ordered so that one spare structure will be available. About 60% of the disks have already been annealed and are ready for final machining. In parallel, diffusion bonding tests are performed in a 1 bar dry hydrogen furnace. The objective is to have the three structures ready for installation in spring 2011.

CONCLUSION AND OUTLOOK

A new wakefield monitor design has been presented. It is integrated to the CLIC main linac accelerating structure without any major change. The proposed wakefield monitor allows to study two kinds of hybrid HEM modes at the same time. Time domain computations have shown that a resolution of 5 µm is achievable with TE like modes generated around 24 GHz. The mechanical design has taken into account the required high gradient fabrication technologies of normal conductive cavities as well as the integration constraints in the CTF3 environment. The manufacturing should be finished by the end of 2010 so that low level rf tests and installation in the vacuum tank will occur in spring 2011. In parallel, the electronic acquisition system under development at CERN will be installed and first tests with beam and high power RF from PETS are expected in 2011.

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