HIGH BANDWIDTH WALL CURRENT MONITOR FOR CTF3*

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Abstract

Wall Current Monitors (WCM) are commonly used to observe the time profile and spectra of a particle beam by detecting its image current. Within the framework of the EUROTeV Programme, a WCM for CLIC and ILC having a very large bandwidth (100kHz-20GHz) is required and has been developed. A deep study of the field configuration for the device has been necessary. Consequently, the geometrical parameters crucial for a proper functioning of the structure have been found. Furthermore, the very stringent initial requests (bandwidth from 100kHz to 20GHz) were reviewed in a more critical way showing that the low frequency cutoff can be sensibly increased, thus avoiding any ferrite in the structure.

INTRODUCTION

The working principle of the proposed structure is shown in figure 1: the electromagnetic field dragged by the bunches passes in a small longitudinal gap made on the wall pipe and it is "shaved". A part of this portion of the electromagnetic field is captured by a coaxial antenna in the first section of a bigger coaxial line, while the rest is damped along the line.

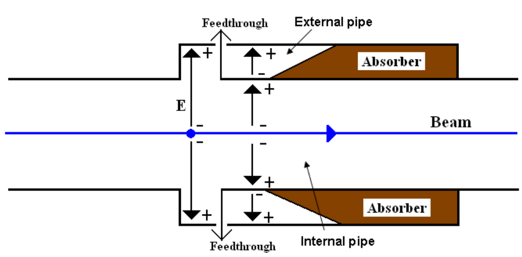

Figure 1: Principle scheme of the proposed structure.

The stringent requests of ILC and especially CLIC beams translate into tight requirements of beam diagnostics device performances. In fact, because of the quite short bunch spacing in CLIC, the WCM needs a very high frequency cutoff of 20GHz, with, in principle, a very large bandwidth from 100kHz to 20GHz. Allowing for these high frequencies, a profound study of the field configurations for the device is necessary in order to pin down the geometrical parameters crucial for a proper functioning of the structure.

In reality, this very stringent initial requests, especially for the low frequency cutoff, have to be reviewed in a more critical way. The value of 100kHz was chosen because of the very long bunch train length in the Drive Beam Linac of the 3rd CLIC Test Facility (CTF3) at CERN (1.54μs, namely $\approx$700kHz in frequency). In practice the main effect of the low frequency cutoff, f_{low}, is to give an exponential droop of the signal with a time constant $\tau_L = 1/3f_{low}$. This effect could be dangerous only if the droop time constant τ_L is comparable or lower than the bunch length in time; but this is not the case because of the very short expected r.m.s. bunch length for CTF3 of 5ps[1]. More important is the bandwidth which is the merit figure for a correct signal recovering in time.

In the following we shall discuss the results of the field analysis and we shall present our High Bandwidth Wall Current Monitor (WBCM). Some considerations on the correct signal recovering will be done and, finally, by using an *ad hoc* code in Matlab, we shall give a numerical example by applying the "real" WBCM transfer function to a CLIC-like bunch train, showing that the signal is fully recovered.

FIELD ANALYSIS

A full field analysis can be found in [1]. From this analysis one learns that there are two reflection sources: the different cross sections between internal and external pipe and the presence of the feedthrough's. As an initial approach, it is possible to analyze these effects separately as done in [2]. The result of this analysis is that the different cross section between the two pipes does not allow all the possible field configurations to propagate from the inner to the outer pipe. This will produce reflections at the level of the gap (*gap resonances*). They can be cured by using a tapering in order to smooth this transition as shown in figure 2, in which it has also to be noted that the reflections appearing at $\approx$7GHz and $\approx$14GHz correspond to the cutoff of the first two TM modes of the internal coaxial.

The presence of the feedthrough's gives two effects. The first one is that, when the distance between two feedthrough's becomes equal to the free space wavelength, the first azimuthal resonance (*feedtrough resonances*, F_{feed}) appears in the structure with the following rule:

$$F_{feed} = \frac{c}{d_{feed}}, \qquad \text{with} \qquad d_{feed} = \frac{2\pi r}{n} \qquad (1)$$

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[1] The ILC and CLIC final values are even lower of 1ps and 0.133ps, respectively.

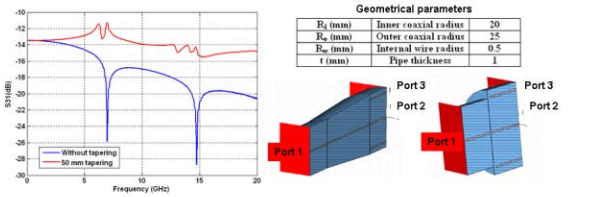

Figure 2: *Gap resonances* comparison between a 50mm tapered structure (red line) and a non tapered structure (blue line).

where c is the speed of light, n is the number of feedthrough's and r is the height of the feedthrough radius from the center. It is straightforward that by increasing the number of feedthrough's, the first *feedthrough resonance* will be pushed to higher frequencies. For a structure having the same dimension as in figure 2, by choosing n=16 this resonance is pushed up to 33GHz. A second effect is that, when the feedthrough's are added to the tapered structure, the *gap resonances* exhibits an enhancement as shown in figure 3.

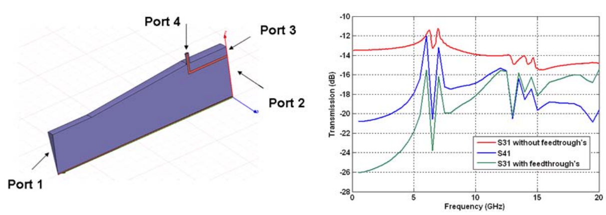

Figure 3: Scattering parameters of the whole structure with and without feedthrough's (red line).

This happens because the presence of the feedthrough's prevents the modes to freely pass from the inner to the outer pipe. To reproduce the same results of a structure without feedthrough's (figure 2) one should fulfill the following condition

$$d_{feed} = \frac{2\pi}{n} r \geq \lambda_{TM01_{cutoff}} \quad (2)$$

where $\lambda_{TM01_{cutoff}}$ is the wavelength of the first TM mode cutoff of the internal pipe.

Finally, from the field analysis, we get two requirements in conflict one to each other as follows

$$\begin{array}{cc} \textit{Feedthrough resonance} & \textit{Gap resonance} \\ F_{feed} = \dfrac{c}{d_{feed}} & d_{feed} \geq \lambda_{TM01_{cutoff}}. \end{array} \quad (3)$$

As an example: if we want to push beyond 20GHz the first F_{feed}, we need d_{feed} <15cm which does not fulfill the *gap resonance* condition in eq.(3) since, in this case, it is $d_{feed} < \lambda_{TM01_{cutoff}}$ =43.5cm.

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It is possible to overcome the *impasse* on the d_{feed} value found in the previous section in two ways [1]: by reducing the outer pipe aperture in order to permit the *gap resonances* excited at its edge to run back in the beam pipe; by playing with the field configurations of a double coaxial waveguide, in order to avoid the *gap resonances* enhancement. Since, in our case, any aperture reduction is not acceptable, a structure based on the second scheme has been fully developed.

The working principle is shown in figure 4: the intermediate pipe (inner pipe in the figure) reflects back at the surface *A* the TM modes coming from the beam pipe, and thus *shields* the feedthrough's and avoids the enhancement of the reflections as in figure 3.

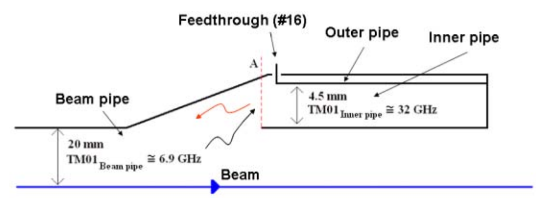

Figure 4: Working principle of the structure.

A comparison between a structure with and without the shielding pipe is presented in figure 5.

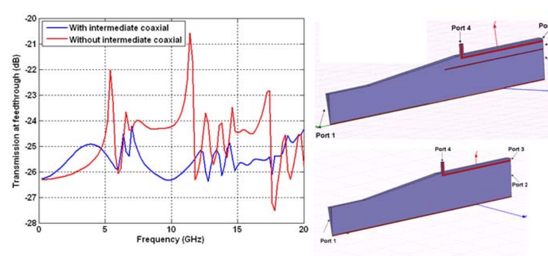

Figure 5: Comparison between a structure with and without the shielding pipe.

In order to absorb the e-m radiation going into the inner and outer pipes, two layers of SiC have been used. In figure 6, the new structure and the transmission at the feedthrough are shown: the signal is quite flat at a level of -24dB±2dB in the range 2GHz-20GHz without using any ferrite. Furthermore the low frequency cutoff can be lowered down to 400MHz by an external circuit. In figure 7, real and imaginary part of the longitudinal coupling impedance, evaluated by means of the improved log-formula [3], are given, showing very low values.

SIGNAL RECOVERING

Here we make some brief consideration on the merit figure to look at for a proper signal recovering, which means for us to recover the bunch train shape with its correct bunch spacing.

As already mentioned the effect of a higher low frequency cutoff is to give a droop of the recovered signal without any important consequence if, as in our case, the droop time constant is bigger than the bunch length in time.

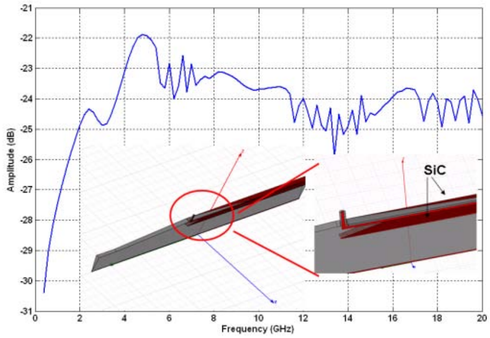

Figure 6: Final structure with SiC.

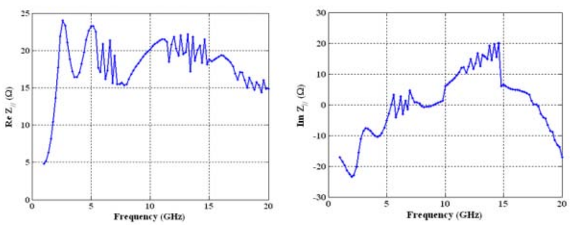

Figure 7: Real and Imaginary part of the longitudinal coupling impedance.

Very important for a correct signal recovering is the bandwidth. Indeed a correct signal recovering will happen if one is able to detect the first harmonic peak or at least two adjacent peaks in the spectrum at higher frequencies. If a certain number of bunches are periodically lost the new spectrum will present the first harmonic at a lower frequency and a shorter frequency separation between the harmonic peaks (larger bunch separation in time). Therefore for a proper recovering of the signal one should be able to detect this "new" first harmonic at a lower frequency or two adjacent harmonics at higher frequencies. This means that, for a correct signal recovering, the bandwidth should be able to follow this frequency shift. The minimum required bandwidth is fixed by one half of the highest frequency that we want to detect. In our case the minimum required bandwidth is of 6GHz determined by CLIC Drive Beam with its 83ps of bunch spacing (12GHz) representing the worst case since the bunch spacing for the CLIC Main Beam is 500ps (≈2GHz) while for ILC beams it is 369.2ns (≈3MHz).

In figure 8, a numerical "measurement" is shown: we apply to the spectrum of a CLIC-like Drive Beam the transfer function of our WBCM and we make the inverse Fourier transform of the obtained signal. The result shows that, apart the initial droop that can be in any case compensated, our WBCM is able to recover either the bunch shape or the bunch spacing.

CONCLUSION

The development of a 20GHz WBCM has reached its final phase. The electromagnetic fundamental relations for

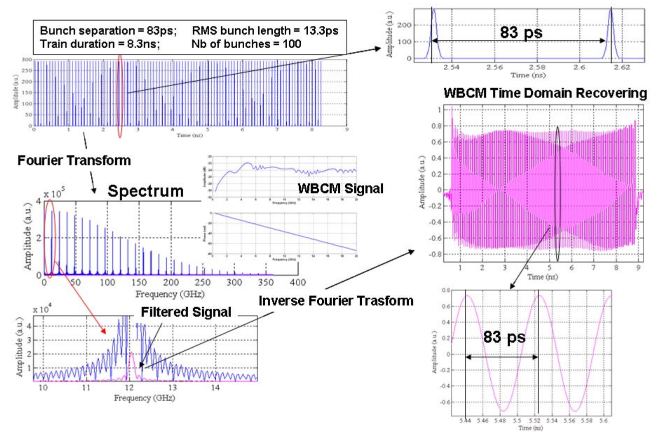

Figure 8: WBCM CLIC-like Drive Beam signal recovering.

this kind of devices have been found. The designed structure presents a quite flat behavior of the signal transmission at the feedthrough's staying in a range of ±2dB around -24dB, in a frequency range from 2GHz to 20GHz and very low values of the longitudinal coupling impedance. The mechanical design is finished and all the parts for one prototype have been ordered.

Furthermore the initial very stringent specifications on the low frequency cutoff (100kHz) have been reviewed in a more critical way. From this analysis comes out that the merit figure for the signal recovering is the bandwidth. The minimum required bandwidth is fixed by one half of the highest frequency that we want to detect. In our case the minimum required bandwidth is of 6GHz determined by CLIC Drive Beam with its 83ps of bunch spacing (12GHz) representing our worst case. The expected high frequency cutoff of the proposed WBCM is 20GHz while the expected low frequency cutoff is 2GHz (with the possibility of lowering it down to 400MHz by means of external circuits) which gives a very large bandwidth of 18GHz able to fully accomplish the signal recovering with the further simplification of avoiding any ferrite in the structure.

ACKNOWLEDGEMENTS

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REFERENCES

[1] A. D'Elia, R. Fandos, L. Soby, "High Bandwidth Wall Current Monitor", EUROTeV report, in preparation.

[2] T. Kroyer, "*A Structure for a Wide Band Wall Current Monitor*", AB-Note-2006-040 RF.

[3] V. G. Vaccaro, "*Coupling impedance measurements: an improved wire method*", INFN-TC-94-023.