EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN - AB Division

CERN-AB-2003-063 BDI

CLIC Note 575

CTF3 Note 055

A NEW WIDE BAND WALL CURRENT MONITOR

P. Odier
CERN, 1211 Geneva 23, Switzerland

Abstract

Wall current monitors (WCM) are commonly used to observe the time profile of particle beams. In CTF3, a test facility for the CERN Linear Collider study CLIC, high current electron beams of 1.5 microseconds pulse length are bunched at 3 GHz and accelerated in a Linac working in fully loaded mode, for which a detailed knowledge of the time structure along the pulse is mandatory. The WCM design is based on an earlier version developed for CTF2, a previous phase of the test facility, in which the beam duration was only 16 ns. Due to the longer pulse width the low frequency cut-off must be lowered to 10 KHz while the high frequency cut-off must remain at 10 GHz. The new WCM therefore has two outputs: a direct one for which an increase of the inductance results in a 10 GHz to 250 kHz bandwidth while the second one, using an active integrator compensating the residual droop, provides a 10 kHz to 300 MHz bandwidth. The new WCM has been installed in CTF2 late 2002 in order to test its high frequency capabilities prior to its use in CTF3. Design considerations and first results are presented.

Presented at DIPAC 2003, Mainz, Germany, 5 - 7th May 2003

Geneva, Switzerland
19 June 2003

A NEW WIDE BAND WALL CURRENT MONITOR

P.Odier CERN, Geneva, Switzerland

Abstract

Wall current monitors (WCM) are commonly used to observe the time profile of particle beams. In CTF3, a test facility for the CERN Linear Collider study CLIC, high current electron beams of 1.5 µs pulse length are bunched at 3 GHz and accelerated in a Linac working in fully loaded mode, for which a detailed knowledge of the time structure along the pulse is mandatory. The WCM design is based on an earlier version developed for CTF2, a previous phase of the test facility, in which the beam duration was only 16 ns. Due to the longer pulse width the low frequency cut-off must be lowered to 10 KHz while the high frequency cut-off must remain at 10 GHz. The new WCM therefore has two outputs: a direct one for which an increase of the inductance results in a 10 GHz to 250 kHz bandwidth while the second one, using an active integrator compensating the residual droop, provides a 10 kHz to 300 MHz bandwidth. The new WCM has been installed in CTF2 late 2002 in order to test its high frequency capabilities prior to its use in CTF3. Design considerations and first results are presented.

1 INTRODUCTION

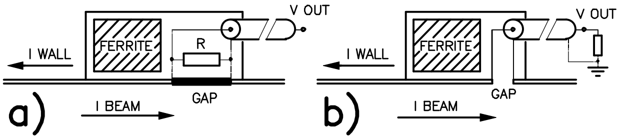
In CTF3, the test facility for the CERN Linear Collider study, high current electron beams of 1.5 µs pulse length are bunched at 3 GHz and accelerated in a Linac working in fully loaded mode, for which a detailed knowledge of the time structure along the pulse is mandatory. The new WCM design is based on an earlier version developed for CTF2 a previous phase of the test facility[1,2], in which the beam duration was only 16 ns.

The 1,5 µs pulse duration in CTF3, much larger than in CTF2, requires a significant decrease of the WCM low frequency cut-off, down to 10 kHz in order to limit the signal droop along the pulse. The high frequency cut-off should remain 10 GHz since the bunch repetition frequency will be 3 GHz. Owing to limited space availability, the overall length of the WCM should not exceed 260 mm. The monitor sensitivity is not a critical parameter in CTF3 since the mean beam current during the pulse is high enough, 1.5 A to 35 A.

2 DESCRIPTION OF THE NEW WCM

2.1 Principle of WCM

The general principle of resistive wall current monitor is very simple. A resistor is connected, either directly (Fig.1a) or through a vacuum feedthrough and a cable (Fig.1b) across a gap made in the wall of the vacuum pipe.



Figures 1a and 1b: principle of WCM

The image current, which accompanies the beam along the inside of the vacuum pipe develops a voltage across the resistor. A screening box filled with magnetic material, usually ferrite, is electrically connected on the two sides to force the image current to pass through the resistor. The equivalent circuit of such an arrangement is shown in Fig.2.

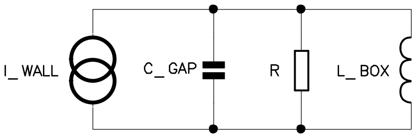


Figure 2: equivalent circuit

The dependence of the observed signal to beam radial position is minimised by collecting and summing the image current in 8 places around the gap circumference using 8 feedthroughs and an external combiner.

2.2 Bandwidth limitations

The high frequency cut-off depends on C_{gap} and on R. The standard connectors and coaxial cables being 50 Ω and the number of outputs being limited to 8 by the physical size of the monitor, the value of R is 50 Ω/8 = 6.3 Ω. For a given vacuum pipe diameter, the value of C_{gap} depends on the length of the gap and on the permittivity of the insulator. In principle the gap length should be smaller than the beam length, which is 1.5 mm rms in CTF3. For practical reason the gap length has been fixed to 2 mm. It is made of a simple cut in the vacuum pipe; the capacitance of a ceramic gap would have been too high for the expected frequency bandwidth. For this reason the connections as in Fig. 1b have been chosen.

The low frequency cut-off depends on R, already mentioned, and on L the inductance of the screening box, which should be increased for CTF3 purpose.

2.3 Vacuum issues

The pressure required in the linac is in the region of 10^{-7} mbar and lower than 10^{-8} mbar in the combiner ring. With no ceramic gap in the WCM the interior of the screening box is under vacuum. This imposes a 150 ºC bake-out process and determines the type of ferrite to be used. In order to avoid virtual leakages, particular care has been taken with respect to welding from inside as well as the introduction of space between the ferrite rings to increase the vacuum conductivity.

2.4 Ferrite and Inductance issues

One of the important purposes of the ferrite is to absorb the λ/4 resonances created inside the screening box. The other purpose is to have a high permittivity to help in producing the high inductance needed to decrease the low frequency cut-off. Thus, the elements determining the choice of the ferrite are:

- Microwave absorption on a wide frequency spectrum in the GHz range
- Tolerate up to 150 ºC
- Desorption as low as possible
- Permeability μ as high as possible

Nowadays the choice of ferrite fulfilling these requirements is quite small. The quality used for the CTF2 WCM being no longer available, the quality #61 from Fair-Rite® has been used. Unfortunately it has a permeability 3 times lower than the one used in the CTF2 WCM which does not allow the expected inductance increase by enlarging the ferrite volume.

The circular shape ferrites needed to fill the screening box have been difficult to machine from tiles and some were destroyed during the production.

2.5 Feedthrough

For the WCM high frequency behaviour, the vacuum feedthrough should behave as a 50 Ω transmission line on a very wide frequency bandwidth; furthermore it should accept the 150 ºC bake-out. The same type as for CTF2 has been adopted [3].

2.6 Mechanics

The cross-section of the WCM on Fig.3 shows the 2 mm width gap, the feedthroughs and the stack of ferrites in the screening box.

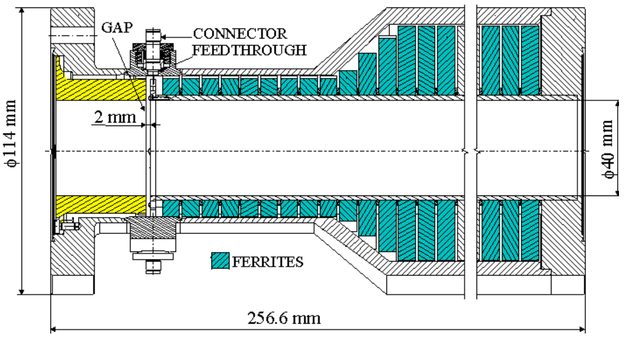


Figure 3: WCM general cross-section

2.7 External combiner and Integrator

The 8 outputs of the WCM are binary combined [4] using 50 Ω semi-rigid cables and combiners. They are carefully adjusted to provide an output sum signal independent of the beam position in the WCM and with minimum time dispersion. On a second output an active integrator compensating the residual droop provides a 10 kHz to 300 MHz bandwidth.

In Fig.4 we see the 8 outputs of the WCM connected through the combiner to the direct output and to the integrator.

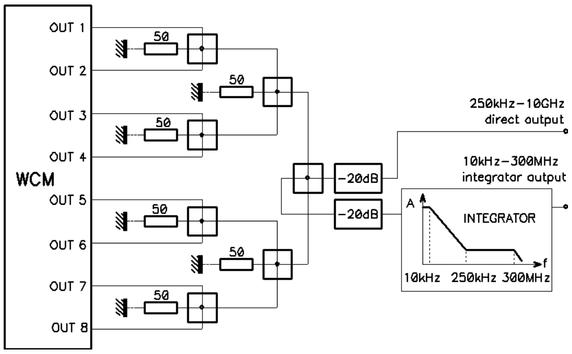


Figure 4: WCM general layout

Table 1 summarises the WCM specifications:

Table 1: WCM Specifications

Impedance	4 Ω
Low-frequency cut-off, direct output	10 kHz
Low-frequency cut-off, integrator output	250 kHz
High-frequency cut-off	10 GHz
Number of feedthroughs	8
Gap length	2 mm
Beam aperture diameter	40 mm
Length	256 mm
Flange type	DN63CF
Max temperature for bake-out	150 ºC

3 RESULTS

3.1 Laboratory test results

The WCM has been tested in laboratory on 2 different test-benches [5]:

1. A time-gated test-bench for high frequencies where very short pulses are applied to a non terminated thin wire passing through the WCM. The WCM pulse response is then observed during the short time before the reflections occur.

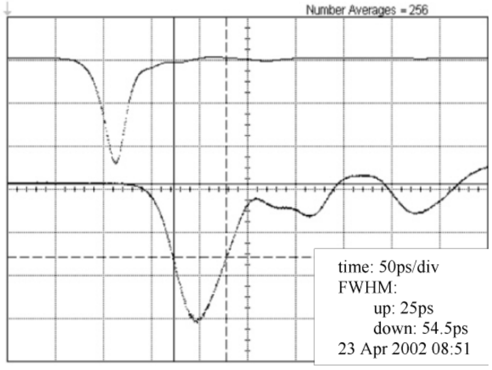


Figure 5: Pulse response of the prototype

In Fig.5, the upper trace is the pulse at the input of the test-set (FWHM=25 ps) and the lower trace is the WCM response measured on a 20 GHz scope after a 1 meter long cable (FWHM=55 ps, thus the WCM equivalent high frequency cut-off is 7.7 GHz).

2. A coaxial test-bench for middle and low frequencies where a step function is applied to a 50 Ω coaxial structure mounted upstream and downstream the WCM being tested. The low frequency cut-off is calculated from the measurement of the exponential decay.

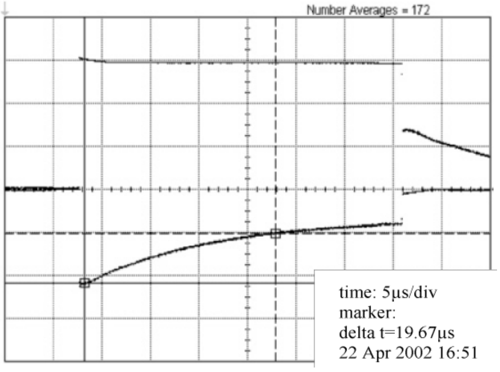


Figure 6: Step response of prototype + integrator

In Fig.6, the upper trace is the 33 µs pulse at the input of the test-set and the lower trace is the WCM response seen after the integrator (τ=19.7 µs, thus the low frequency cut-off is 8kHz).

3.2 Results obtained with beam

Since CTF3 will start only in May 2003, the new WCM has been installed in CTF2 in November 2002 (Fig.7) in order to test its high frequency capabilities under real beam conditions.

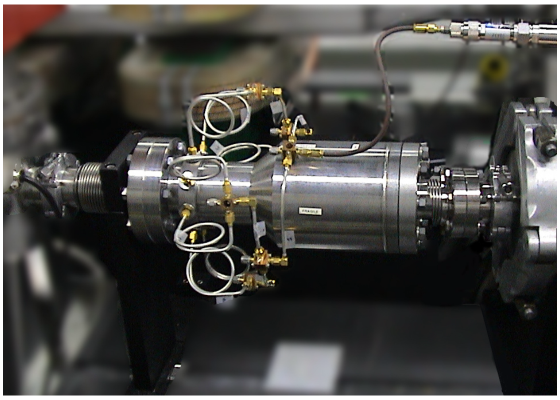


Figure 7: WCM in CTF2

The measurement made after 17 meters of low loss coaxial cable on a 20 GHz sampling scope is shown on Fig.8. (beam conditions:1 bunch, charge=0.8 nC, FWHM=15 ps). The pulse response is close to the one obtained on the time-gated bench-test in the laboratory but degraded by the cable. A ringing after the pulse indicates a likely resonance in the screening box or in the feedthrough. Nevertheless, the 97 ps FWHM shows the very fast time response of the WCM.

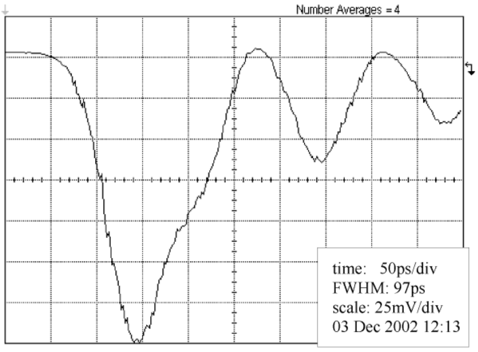


Figure 8: WCM signal on CTF2 beam

4 CONCLUSIONS AND OUTLOOK

The test performed on CTF2 has been successfully accomplished and proved that the design modifications to lower the WCM low frequency cut-off do not affect its high frequency behaviour. Some improvement remains to be made to reduce the 6 GHz resonance.

Two WCMs will be installed in CTF3 in July 2003. A series of 14 units will be prepared for installation in the future CTF3 stages. A new process of machining the extremely hard ferrite tiles (high pressure water jet) will be tested to reduce the tiles breakage.

5 ACKNOWLEDGMENTS

I would like to thank Jacques Durand for having passed on a technically sound and interesting project and for having been so patient in explaining the numerous details of this monitor. Jean-Pierre Potier is acknowledged for his encouragements for writing this paper. Elie Chazarenc and Luigi Leggiero are thanked respectively for the mechanical study and for the very accurate Electron-Beam Weldings.

6 REFERENCES

[1] J. Durand, H. Braun, “Wall Current Monitors for CTF3”, CERN CTF3-Note-014, 2000

[2] J. Durand, T Tardy, M. Wurgel, “A 10 GHz Wall Current Monitor”, CERN PS/LP/Note 95-09, 1995

[3] J. Durand, T.Tardy, R. Trabelsi, “A miniature ultrahigh vacuum feedthrough usable from DC to 20 GHz”, CERN PS/LP/Note 96-09, 1996

[4] J. Durand, “Combining Wideband Signals from a Wall Current Monitor”, CERN PS/LP/Note 94-14, 1994

[5] J. Durand, “Prototype “froid” WCM CTF3: quelques résultats”, CERN CTF3_note_041, 2002