CHARACTERISATION OF FAST FARADAY CUPS AT THE ELETTRA LINAC

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Abstract

Since several years, the Diagnostic Group at Laboratori Nazionali di Legnaro (LNL) has been designing Fast Faraday Cups (FFC) to be used on their Heavy Ion Accelerators. Latest developments in this field include a Stripline FFC, jointly developed with the Spallation Neutron Source (SNS). A collaborative partnership has been set-up between LNL and the ELETTRA Laboratory to fully characterize new FFCs, using the 1GeV electron Linac in operation at the ELETTRA Synchrotron Light Source. Two FFCs, the stripline FFC, built at SNS, and a coaxial FFC, made at LNL, have been installed at ELETTRA who provided the wideband data acquisition and the remote control of the measurement. The first measurements, carried out using a 1GHz oscilloscope, have allowed the proper set-up of the instrument remote control as well as a low jitter triggering system, synchronous with the injected electrons. Wideband measurements were performed using oscilloscopes with bandwidths up to 20GHz, whereas the bandwidth of the Stripline FFC has been estimated to be roughly 20GHz.

A complete set of tests was carried out both on the coaxial FFC and on the stripline FFC. Moreover, thanks to the information provided by these wideband measurements, the Linac working point has been further optimized as well as the injection process into the ELETTRA Storage Ring.

INTRODUCTION

The ELETTRA Linac [1] is in operation since 1992 as injector of the ELETTRA Storage Ring, providing a 1.0GeV electron beam. Since 1996 [2] the Linac has also been used parasitically as a "test facility" both for material irradiation experiments and for testing diagnostic equipments [3]. The characterization of the new Fast Faraday Cups was carried out in the frame of this second activity.

The FFCs, designed to have information on beam temporal structure, have been developed at LNL for several years to measure the bunch length of ion beams. The experience gained in that field also yielded a collaboration with the SNS project at Oak Ridge, where a strip line FFC has been developed to measure the bunch length out of the low energy (E=2.5MeV of H^-) section of the machine.

The ELETTRA Linac bunching structure

The bunching section of the ELETTRA Linac, shown in Fig. 1, includes:

- a 500MHz Sub Harmonic Chopper (TM_{110} deflecting cavity)
- a 500MHz Buncher (TM_{101} pill box cavity)
- 3GHz Pre-Buncher (TM_{101} pill box cavity)
- 3GHz Buncher (0.4m long $2/3\pi$ SW accelerating section)

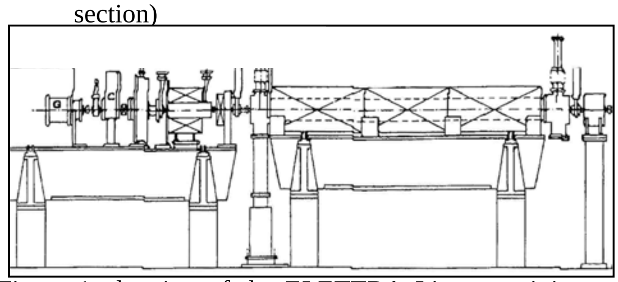

Figure 1: drawing of the ELETTRA Linac pre-injector: G=Gun, C=Chopper, PB5=Pre-buncher @500MHz, PB3= Pre-buncher @3GHz, B=Buncher @3GHz

With a proper setting of the parameters (amplitude and phase of the cavities) this configuration allows to select and fill a pure 500 MHz bucket of the Storage ring, in single bunch mode. This means that at the Linac exit all the charge is compressed in less than 1 nsec with a 3 GHz fine structure of the beam (2 or 3 S-Band micro-bunches, spaced by 330 ps). As we have observed with those measurements, changing the relative phases between the 500MHz cavities and the 3GHz ones, it is possible to change the number and the relative amplitude of the S-Band micro bunches.

THE FAST FARADAY CUPS

The FFC station, built at LNL and holding the two FFCs, has been installed on the Linac User port at 1GeV (fig. 2). An already available fluorescent screen located upstream the station has been used for alignment purposes and for checking the electron beam focusing.

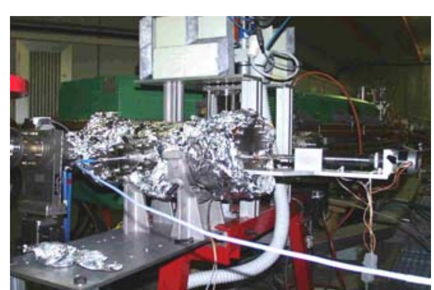

Figure 2: view of the FFC station installed on the Linac User port at 1GeV. The cable of the coaxial FFC is visible in the foreground. On the right hand side, there is the linear translation stage of the Stripline FFC.

The Coaxial Fast Faraday Cup

The coaxial Fast Faraday Cup adopts a 50Ω SMA vacuum feed-through from Caburn MDC Company (ref. SMAD, part number 9251001), welded on a CF16 flange and put directly on beam axis on the user port at 1GeV: the central pin acts as a fixed "cup". The CF16 flange is isolated from the beam pipe by a ceramic break; during the tests it has been shorted to ground the cup.

The Stripline Fast Faraday Cup

The stripline FFC (fig. 3) was designed by optimizing the electromagnetic-match of the beam-target to the connecting stripline circuit. This was performed iteratively using HFSS and showed a broadband match of –25 dB to over 50 GHz. The top and bottom grounds of stripline isolated the FFC signal from a noisy environment and consequently lowered the noise level.

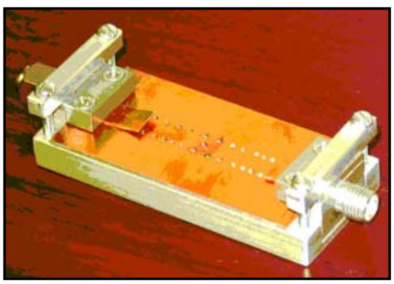

Figure 3: the stripline FFC developed at SNS: the output port is visible on the right, 50Ω termination on the left.

The grounds were stitched together in a random manner so that signal propagation resonances do not build up along the circuit card. The launch onto the circuit board from the coaxial cable was hand-matched using small tuning pieces of copper and measured using an Agilent 8722 operated in the time domain. The resulting launch and target have a reflection coefficient of better than –25dB to 40GHz. The overall thickness of the circuit board was set to 0.50mm and the length is about 50mm.

Signal generation process

The measurements presented in this paper have been obtained with 900MeV electrons: most of the electron energy [4] is lost via Bremsstrahlung (gamma rays + electron of lower energy), which we do not detect. Successively, lower energy electrons produce ions via electron-atom collisions. Missing valence electrons are supplied through the cable resulting in a positive pulse measurement. It is worthwhile noting that both central pin and surrounding "ground" are likely to be invested by the 900MeV beam. In fact, the diameter D of the SMA standard (IEC169-15, $D_{jack-female}$=1.24 to 1.29mm) is smaller than the beam diameter (±2σ=2 to 3mm) which has been measured on the Fluorescent screen just in front of the FFC station. Therefore, as we are measuring the signal of the central pin relative to the "ground", depending on the ratio of central pin signal to "ground" signal we observed both positive and negative pulses.

MEASUREMENT SET-UP

The driving criteria for the measurement set-up were to locate the oscilloscope as close as possible to the measurement point and to cure noise, both E.M. and from secondary radiation. After some preliminary tests, the final configuration included:

- the FFCs station located in the Linac Tunnel at E=1GeV (see fig. 2)
- the Tunnel Station, close to measurement point, where the oscilloscopes have been placed
- the Remote Station, in the Linac Control Room

The Tunnel Station: oscilloscopes and triggers

The Tunnel Station is located close to the 1GeV point, to minimize cable effects on the measurement bandwidth, but outside the Tunnel, to avoid long-term radiation damage to the used instruments. The Remote Station is dedicated to the remote control of the oscilloscope and to data storage. The distance between these two stations is 150m and they are linked with a fibre optic Ethernet. The Linac Gun Trigger (f=10HZ), available in the Linac Control room, were delivered to the oscilloscopes using a coaxial cable driven by a fast pulse generator [5], acting also as a programmable delay unit.

Different oscilloscopes were used during the measurements, namely the Tektronix TDS5104 (BW=1GHz), the LeCroy8500-Wavemaster (BW=5GHz) and the Tektronix CSA803A (BW≤50GHz). The first two are real-time, fast sampling oscilloscopes (5GS/s and 20GS/s, respectively) whereas the last one is an ultra-wideband sampling scope, at 200KS/s.

The two real-time oscilloscopes can operate both in single-shot and in "equivalent sampling" mode, reconstructing the waveform over many subsequent trigger events. They can trigger either on external signal or on the signal itself. The CSA803A can trigger only on an external signal and requires an ultra low-jitter trigger typically at a frequency of 100KHz. As the repetition rate is 10Hz and the jitter of the external trigger was estimated to be $50ps_{pk-pk}$, it resulted critical in use.

Most of the fast acquisitions were made with the former two instruments, triggering on the signal itself and in "equivalent sampling" mode. Rather than relying on pulse-to-pulse time stability of the Linac with respect to the Gun Trigger, we profit by the stability of the 3GHz satellites inside each Linac macro pulse.

Time Domain Reflectometer characterization

A Time Domain Reflectometer (based on Tektronix Sampler 7S12 equipped with S-4 sampling head and S-52 Pulse generator on a 7603 scope) has been used to check the impedance of the acquisition structures. The coaxial FFC shows obviously an "open circuit" whereas the Stripline FFC is almost perfectly matched to 50Ω. By expanding the time axis and vertical deflection, we identified from impedance variations the different line components (FFC, connectors and in-vacuum cable).

MEASUREMENT RESULTS

During the early shifts, the Linac was operated in Multi Bunch (MB, a 70ns long macro pulse) to find the proper setting for the trigger-to-beam delay and to align the beam onto the coaxial FFC. After which, Single Bunch mode (SB, 2ns) was preferred as it allowed a clearer signal analysis, avoiding adjacent bunches to interfere with each other. Fig. 4 shows a MB acquisition on the coaxial FFC.

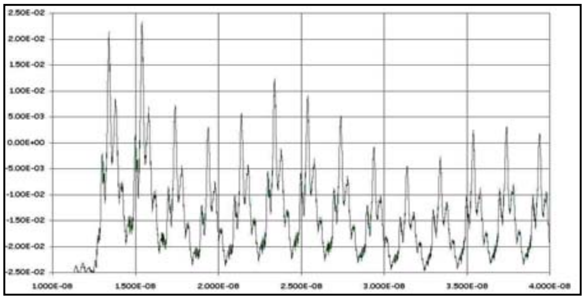

Fig. 4: Multi Bunch Linac macro pulse acquired with the coaxial FFC and the Tek 5104 1GHz oscilloscope. HOR: 5ns/div, VERT: 5mV/div. The 3GHz satellites are clearly visible on both sides of the main bunches.

A SB acquisition with the LeCroy8500 is shown in fig. 5: it is a RIS (Real-time Interleaved Sampling, the Le Croy acronym for “equivalent sampling”) acquisition. The t_{RISE} of the pulse is 95±3ps, corresponding to a bandwidth of 3.66GHz, in agreement with scope data.

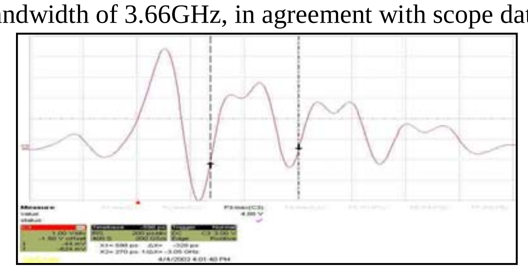

Fig. 5: Single Bunch acquisition, Coaxial FFC+Le Croy 8500 oscilloscope. HOR: RIS 200ps/div, VERT: 1V/div.At V_{phase}=3V, three 3GHz satellites can be observed.

Figure 6 shows a typical acquisition from the stripline FFC. Raw data is shown with no averaging. The jitter of the waveform can be estimated to be <20ps_{pk-pk}.

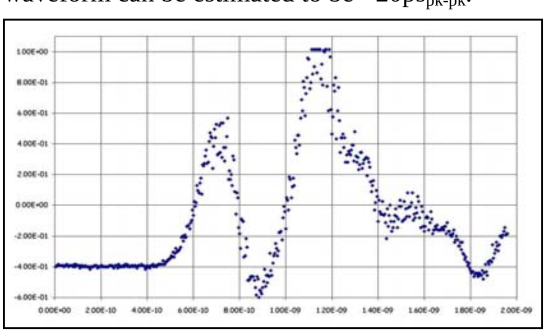

Figure 6: raw data from stripline FFC+Tek 5104. HOR: Eq. Time 200ps/div, VERT: 200mV/div. Two satellites are clearly visible. ΔT is >330ps due to oscillatory pulse response.

Sub Harmonic Pre-Buncher phase variation.

A set of measurements has been carried out while changing the phase (V_{phase}) of the 500MHz SH-PB with respect to the 3GHz Buncher. The three satellite (at 0 and ±330ps) amplitudes changed by changing V_{phase} over a 2V interval, until a single satellite was measured.

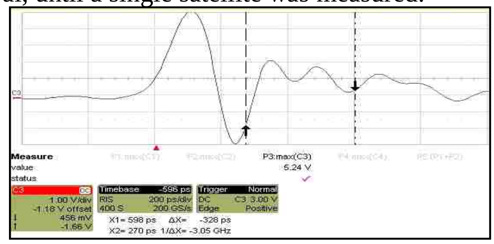

Fig. 7: Single Bunch: acquisition from Coaxial FFC+Le Croy 8500; HOR: RIS 200ps/div, VERT: 1V/div. At V_{phase}=2.7V, one main 3GHz satellite appears.

Data analysis tool

To analyse the waveforms obtained with different settings of the V_{phase}, a dedicated analysis tool was developed using NI LabView. After having loaded the “single satellite” waveform (fig. 7), individually scaled replicas are summed up, each shifted in time by 330ps. The “shift & sum” process is shown on fig. 8, left. The resulting waveform is shown on fig. 8, right, which is in good agreement with the acquisition of fig. 5.

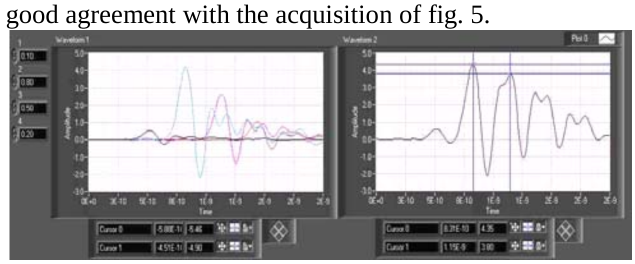

Fig. 8: reconstruction process with four satellites.

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