MICROWAVE PICKUPS FOR THE OBSERVATION OF MULTI GHZ SIGNALS INDUCED BY THE ESRF STORAGE RING ELECTRON BUNCHES

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Abstract

The length of the bunches stored in ESRF lies in the 30 ps to 120 ps range (FWHM). The observation of single bunch phenomena like transverse or longitudinal oscillations or bunch length variation requires the acquisition and analysis of signals at frequencies higher than 10 GHz. A set of microwave cavity pick ups operating at 10 GHz and 16 GHz together with the appropriate electronics has been implemented on the ESRF storage ring; it detects the wall currents on the vacuum chamber due to the electron beams circulation. We describe the design of these cavities, give the result and analysis of measurements performed with the pick ups and indicate how we plan to use these devices as beam diagnostics

1 SINGLE BUNCH SIGNALS

Some examples of single bunch oscillation simulations are shown in the figure 1 (longitudinal oscillation) and 2 (transverse oscillation).

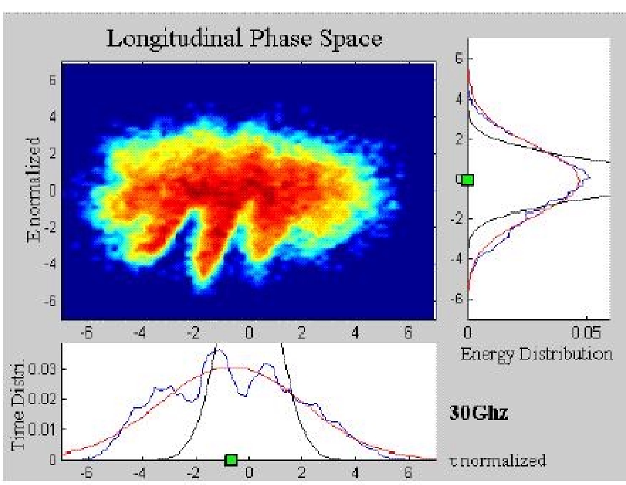

Figure 1: simulation of a microwave longitudinal instability caused by a 30 GHz broadband impedance [1]

For bunch lengths in the 30 ps to 120 ps range, the spectrum of the image currents of the bunch on the vacuum chamber will extend up to tens of gigahertz. However, especially in single bunch filling, the pattern of this spectrum is very repetitive: the parameters of interest are usually the frequency offset of the side bands of the harmonics of the revolution frequency ; So the analyze of an oscillation will only require the study of a narrow span of the total spectrum, in a part of the spectrum where the line amplitudes will be sufficient to be properly detected. An advantage of detecting the beam signal in a narrow span of its total spectrum is also to reduce the large peak/average level of a single bunch signal, avoiding the saturation of the detection electronics. In order to acquire this narrow bandwidth signals, we have developed and implemented dedicated pick ups on the ESRF storage ring

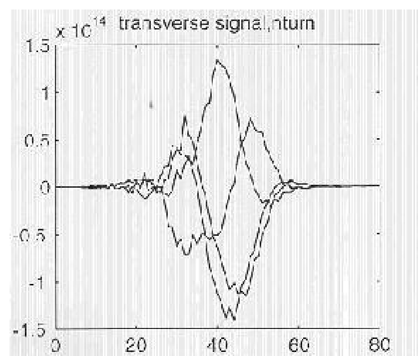

Figure 2: time domain simulation of a short rise time single bunch vertical instability [2] (horizontal scale:1ps/div)

2 PICK UP DESIGN

2.1 General Layout

The pick up principle and mechanical design is shown in the figure 3. The pick up is a 7mm diameter-2mm thick vacuum tight cylindrical iris filled with ceramic. The iris couples the beam image current to the TM010 mode of a pill box cavity. The frequency of this mode is the Nth harmonic of f_{rev}=352.2 MHz, revolution frequency of the beam. The iris diameter and thickness sets the coupling of the cavity to the image current. Two sets have been designed with TM010 mode frequency equal to 29 X f_{RF} = 10.213 GHz and 45 and 45 X f_{RF} = 16.2 GHz. The choice of these frequencies is consistent with the spectrum expected of signals induced by bunches with lengths ranging from 30 ps to 120 ps. The design was optimised using the Agilent HFSS high frequency electromagnetic simulator. By using cavities with different resonating frequencies, we expected to be also able to monitor the variation of the bunch length as function of the bunch charge. The two sets of cavities have been installed on the storage ring. (the set up would allow the mounting of three sets of cavities). The bandwidth of the cavities is 20 MHz for the 10.2 GHz cavity and 30 MHz for the 16.2 GHz cavity.

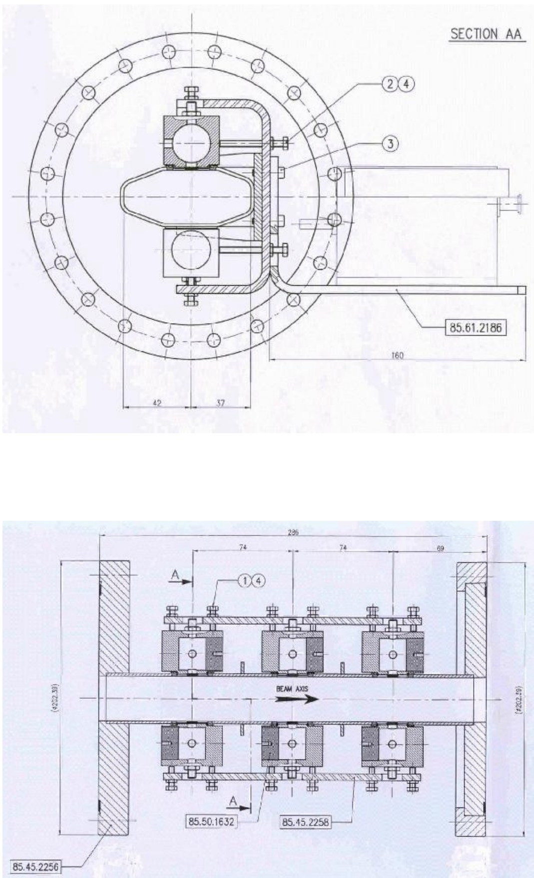

Figure 3:Pick ups front and side view

3 CAVITY SIGNALS DETECTION

The signal from the upper and lower cavity are combined using passive HF combiners to get their sum Σ signal or difference Δ signal. The Σ signal will be used to study the single bunch longitudinal parameters and oscillations of the beam and the Δ signal to study the transverse oscillations. The HF combiner output signals are detected using a 2 stage receiver scheme. The figure 4 shows the layout of the 10.2GHz cavities receiver; the 16.2 GHz cavities receiver is similar. The first stage components are implemented very close to the cavity, on the support visible on the right side of the front view, in order to reduce loses in the connections: The N X f_{RF} signals from the cavities are mixed with a local oscillator signal at (N-1) X f_{rev} to produce a signal at an intermediate frequency IF = f_{rev}. The phase of this (N-1) X f_{RF} signal can be adjusted in order to have its maximum in synchronism, in the mixer, with the signal induced by the center of mass of the bunch, in order to detect the transverse bunch center of mass motion, or in quadrature, in order to detect signals induced by differential head-tail oscillations. The 352.2 MHz output signals of the first stage are sent to the technical gallery, 20 m away, to an homodyne receiver. The 352.2 MHz signal is mixed with a f_{RF} reference signal to perform a vector detection: the in phase detection is used to perform a bipolar detection of the transverse vertical oscillation signal (on the Δ signals) or a detection of the amplitude modulation due for instance to a quadrupolar longitudinal oscillation (on the Σ signals). The quadrature detection is used to study the phase oscillations (on the Σ signal).

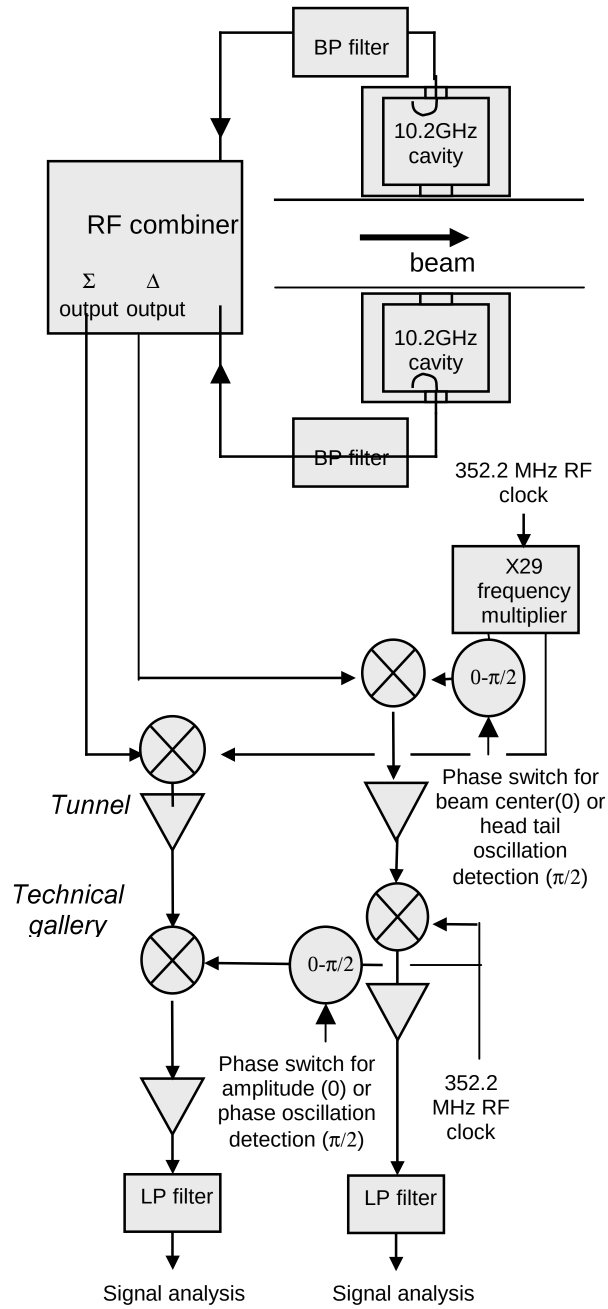

Figure 4: layout of the cavity signals detection electronics (10.2 GHz cavities)

4 SIGNALS MEASURED ON THE ESRF BEAM.

2.1 Longitudinal oscillations

Figure 5a, 5b and 5c shows the spectrums of the 16.2 GHz cavities Σ signal for 5 mA, 10 mA and 16 mA in single bunch filling. The transition from a regime with an incoherent bunch lengthening when the current increases, below 8 mA, to a regime of coherent microwave instability at 10 mA and 16 mA is clearly observable. The synchrotron frequency f_{sync} at ESRF is about 1.6 KHz. The satellites line spacing is 3 X f_{sync} , which seems to indicate a sextupolar mode of oscillation. The signal displayed by the streak camera for the same filling is shown on the figure 5c

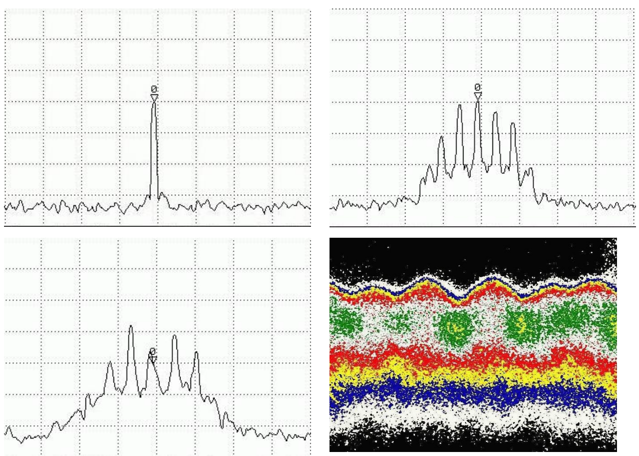

Figure 5a, b, c, d: Spectrums of the Σ signal detected on the 16.2 GHz cavity at 5mA, 10mA, 16mA in single bunch (scale 10 KHz/div-10dB/div) and streak camera image at 16mA (scale: 1000 turns X 150ps).

2.2 Vertical oscillations

Figures 6a and 6b show the signals observed with a 16 X 5 mA filling of the storage ring, with vertical bunch oscillations induced by a 1 MHz BW noise signal applied on a vertical kicker. Figure 6 right shows, for comparison, the spectrum of the signal displayed by the storage ring tune monitor which analyses the modulation of Δ signals coming from 13 mm diameter capacitive electrodes tuned at 352.2 MHz with an RF matching transformer. The figure 6 left shows the spectrums of the product of the Δ HF signal from the 10.2 GHz cavity set, with and without excitation. Though the signal to noise ratio is presently lower with the microwave cavity signals than with the tune monitor signals, the relative sensitivity of the detection of the -1 mode versus 0 mode, with the cavity pick up is much better than with the 352.2 MHz tuned electrodes of the tune monitor, which was the goal of this design. In the future the coupling to the beam of the 10.2 GHz cavities, used to produce the Δ HF signals, will be increased in order to achieve a better signal to noise ratio.

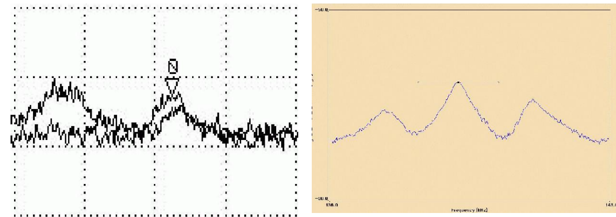

Figure 6: Spectrum of the Δ signal detected on the 10.2 GHz cavity set (left) and spectrum of the signal of the tune monitor (right). Scale:10 dB/div, 1KHz /div

5 CONCLUSION

Following the encouraging results obtained so far, we will implement a remote control of the phases of the different reference oscillator signals in order to provide an easier control of this diagnostic for the accelerator physics studies at ESRF. We plan also to use it in combination with a stripline kicker for single bunch instability feedback experiments [3].

5 CONCLUSION

- The acquisition of signals induced by the image current of the beam the 10 to 16 GHz region of the spectrum with frequency selective cavities allows the study of single bunch phenomenon not easily observable with others type of pick ups.
- This type of pick up is a good complement to the streak camera, particularly for the accurate study of the spectrum of the single bunch signals.

ACKNOWLEDGMENTS

I wish to acknowledge the contribution of Bernard Plan and Bernard Ogier. of the mechanical engineering group for their contribution to the cavity design, and Philippe Arnoux for the implementation of the RF receivers. Discussions with P. Kernel, R. Nagaoka, J.L. Revol helped me a lot to understand the issues of single bunch measurements.

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