DIPOLE MODES STUDY BY MEANS OF HOM COUPLERS AT SBTF

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Abstract

High order modes (HOM) are generated by the interaction of a bunched beam with an accelerator environment. They may act destructively on following particle bunches, leading to an increase of the transverse oscillation amplitude and finally to the deterioration of the emittance. Dipole modes have been studied at the S-Band Test Facility at DESY. One accelerating structure, specially designed for this test linac, is equipped with waveguide pick-ups for measuring the HOMs. For one part of the experiments, a modulation of the transverse offset of the bunches at the structure entrance has been induced using a fast broadband kicker and the effect was measured with a precise stripline BPM. No high impedance modes were clearly found in the structure, which has been detuned and damped by both the tapered geometry of the structure and an absorbing stainless steel coating applied on the iris tips.

1 THE S-BAND TEST FACILITY

The very high luminosity, 10^{33} cm^{-2}s^{-1}, required for future linear colliders presume high charge, small cross section bunches. The main problem is that these bunches strongly interact with the accelerator environment, leading to the excitation of electromagnetic fields, the so-called high order modes (HOM). Off-axis bunches excite transverse HOMs, generating the transverse wake field:

$$\boldsymbol{W}'_\perp(s) = \sum_l 2\boldsymbol{k}'_{\perp\, l} \sin(\omega_l \frac{s}{c}) \exp(-\frac{\omega_l}{2Q_l}\frac{s}{c}), \qquad (1)$$

where $s > 0$ is the distance behind the bunch and ω_l, $\boldsymbol{k}'_{\perp\, l}$ and Q_l are the angular frequency, the transverse loss factor per unit length and the quality factor of mode l.

This wake field acts on the following bunches entering the structure, which leads to the deterioration of the beam properties, mainly to an increase in the emittance and a large energy spread. The modes with a low Q may be damped before the next bunches arrive, so that the main contribution to the wake fields will be given only by the modes with a high $\boldsymbol{k}'_\perp$ and a high Q.

The S-Band Test Facility (SBTF) was built at DESY in the framework of a study of a 500 GeV linear collider based on the S-Band technology [1]. Based on the experience in this frequency range (e.g. SLC), an accelerating structure was specially designed for SBTF, paying attention to reducing the HOMs quality factors. The main purpose of the here described experiments is to find most dangerous HOMs that are excited by using the beam.

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Layout The electron beam is accelerated to a maximum of about 100 MeV by the injector section and a first accelerating structure [2]. The two next accelerating structures, specially designed for this test facility, could give the beam 300 MeV maximum. The first and the second structures are fed through a power splitter by the same klystron [3], while a second klystron feeds a third one.

In Fig. 1 the second accelerating structure, is represented together with a stripline BPM ([4]) which allowed the monitoring of single bunches, distanced by a minimum of 8 ns. A kicker and a steering magnet are placed between the first and the SBTF structures. The current monitors and some elements that were not used during the experiments are not shown. The very fast counter travelling wave kicker [5] can

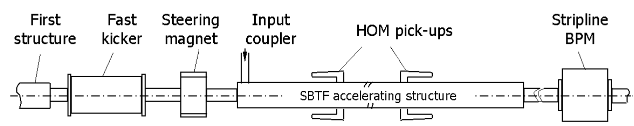

Figure 1: Experimental setup of the kicker experiment

impart on bunches with 35 MeV energy a maximum kick of 400 μrad, which, in case no HOMs act on the bunches, would be seen at the location of the BPM as an offset of 2.4 mm (the autofocusing was taken into account).

The SBTF accelerating structure and HOMs The 6 m long accelerating structure is a constant gradient one, working in the $2\pi/3$ mode at a frequency of 3 GHz. The iris radii are tapered along the 180 cells. In order to avoid phase and amplitude dependent transverse kicks, the input coupler is symmetric and has a power splitter on top.

Special attention has been given to the HOM attenuation. It has been found in simulations that the main contribution to the transverse wake field is given by the modes in the first, third and sixth dipole passbands. While the level of $\boldsymbol{k}'_{\perp\, l}$ in the first passband is of the order of $7.5 \cdot 10^{12}$ V/Cm^2, in the sixth passband a few modes with loss parameters up to $6.8 \cdot 10^{13}$ V/Cm^2 have been found [6].

The frequency detuning induced by the iris tapering leads to the decoherence of the long range wake field. Due to the recoherence effects of the HOMs, damping of the dipole modes is also necessary. On the other hand, modes in the first passband are trapped inside the structure, which makes the use of a few HOM dampers along the structure not efficient. Instead, damping is achieved by covering the iris tips of the cells with a thin stainless steel layer [7, 1]. For the SBTF structures, only the iris tips of cells 1 to 20 and 111 to 121 were covered with such a layer. The calculations made for the first dipole band for a SBTF structure indicate that about half of the modes were damped to Qs less than 5000, while the rest are distributed between 5000 and about 14000, which is the Q level for a pure copper structure. Further damping of the HOMs is provided in the last cells by a colinear load that replaces the output coupler.

The HOM Couplers The first SBTF structure is provided with two HOM couplers with four orthogonal waveguides (cutoff frequency 4 GHz) at one cell for measuring the position of the structure relative to the beam [8] (see Fig. 2). Two opposing waveguides are used for one polarization plane. Azimuthal wall slots are used for coupling.

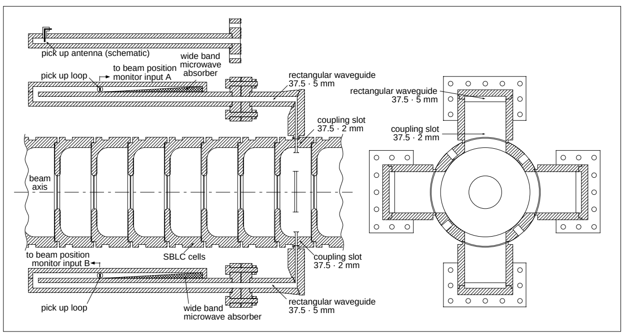

Figure 2: Cross-section of the accelerator structure with a HOM coupler

2 EXPERIMENTAL SETUP

Single-bunch experiments A bunch is shot off-axis through the SBTF accelerating structures exciting wake fields. The signal from the eight HOM coupler waveguides is viewed on both a spectrum analyzer and on an oscilloscope. In order to better reject the strong fundamental mode and other monopole modes, the two horizontal waveguides, as well as the vertical ones, of the first coupler were combined through a magic-T hybrid combiner.

When sweeping the bunch transversely in the structure, the power of a dipole mode will vary as the square of the bunch offset. A minima will be attained when the beam is in the middle of the structure. This can be used to steer the beam in the middle of the structure, or, inversely, to align the structure with respect to the beam axis [1]. Due to the very localized coupling of the modes to the beam, it is even possible to detect the local offset of the structure as a function of the mode frequency.

Multi-bunch experiments When a bunch train is sent off-axis through the structure, some modes add coherently, while others are attenuated. The modes that satisfy the relationship $\omega_l = m\,\omega_b$, where ω_b is the bunch angular frequency and m is an integer, will be strongest excited.

Kicker experiment The aim is to excite only one dipole mode at a time. By means of a fast kicker, a sine modulation is imparted on the transverse offset of the bunches coming out of the first structure. The offsets dx_i of individual bunches at the entrance of the second accelerating section will be then:

$$dx_i = dx_0 \sin(i\omega_K t_b + \varphi), \text{ with } i = 0 \div n-1, \quad (2)$$

where dx_0 is the maximum offset at the entrance of the structure, ω_K is the kicker frequency, t_b is the time interval between the bunches and φ the phase of the first bunch in the train with respect to the kicker signal.

In the accelerating structure a bunch will be deflected by the transverse wake fields excited by all the previous bunches. The kick of bunch i, dx'_i, is given by:

$$dx'_i = \frac{eq_b}{E}\sum_{j=0}^{i-1} W_\perp((i-j)t_b c)dx_0 \sin(j\omega_K t_b + \varphi), \quad (3)$$

where E and q_b are the bunch energy and charge. It was assumed that the change in offset of bunch j is much smaller than dx_j and that the energy gain in the structure is much smaller than the initial energy.

A long bunch train will reach a steady state configuration after the damping length of the highest impedance dipole mode. A resonance will occur when $\omega_K = |m\omega_b - \omega_l|$, where ω_b is the bunch frequency and m an integer [9]. The amplitude of this resonance depends on $\boldsymbol{k}'_{\perp l}$.

3 RESULTS

Single-bunch experiments The spectra of the HOM fields excited by a 1.4 nC bunch have been measured and special attention has been given to the first dipole band. The frequency range seen from the first waveguides is about 4.16 $\div$ 4.3 GHz, while from the second ones is 4.28 $\div$ 4.45 GHz. Interesting to remark is that the fundamental mode could not be seen even before the installation of the power combiners. Two unexpected modes have been seen, one from each coupler, at 4.125 and 4.135 GHz, respectively. They are well separated from the first dipole band and have a much lower Q. Their dipole character has been deduced. These additional modes come from the couplers geometry and are localized around these.

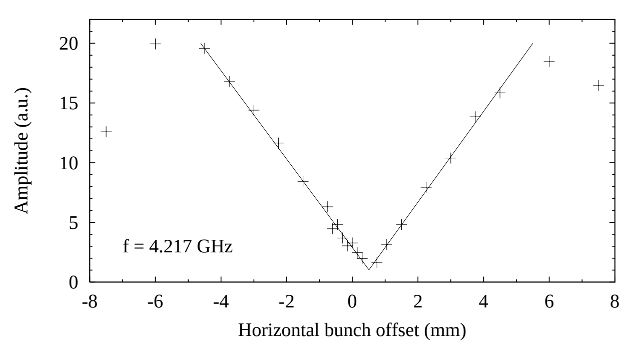

Figure 3: The amplitude of the mode at 4.217 GHz from the horizontal waveguides as a function of the bunch offset

For more modes the signal amplitude was measured as a function of the beam offset. The curve obtained for a mode at 4.217 GHz is shown in Fig. 3. The dipole character can be clearly seen in the linearity of the two sides of the curve. At both sides the signal amplitude decreases due to bunch loss at the irises. The field minima is not 0 because of the misalignment of the structure or a tilt of the beam, meaning that this mode is always excited in some cells. A comparison of the minimum power positions and the geometrical straightness could not be done due to the missing data regarding cell alignment.

Multi-bunch experiments The bunch train was limited to 20 bunches $\times$ 24 ns due to the at the date performances of the klystron. The energy at the entrance of the structure was 65 MeV. For the kicker experiment, the pulse length was prolonged from 0.6 μs to 1 μs (flat top), so that 40 bunches $\times$ 24 ns could be accelerated. In Fig. 4 the spectra from the coupled first horizontal waveguides for 20 bunches $\times$ 24 ns is shown. It can be seen that the modes around 4.125 (the mode induced by the waveguides), 4.167, 4.208 and 4.25 GHz (= $m\omega_b/2\pi$) have higher amplitude than the other ones. Due to the limited number of bunches more modes around these frequencies are amplified.

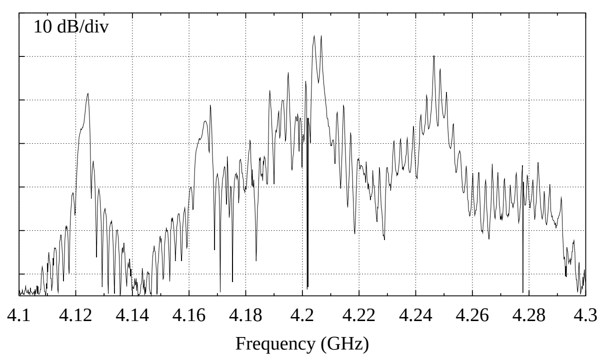

Figure 4: Spectrum from the coupled first horizontal waveguides with 20 bunches $\times$ 24 ns

For the *kicker experiment* a train of 40 bunches with 35 MeV was used. The modulation frequency was varied from 0 to 21 MHz in steps of 0.2 MHz. The difference and the sum signals from the horizontal pick-ups of the stripline BPM were plotted on an oscilloscope. A FFT was performed from the difference signal on the oscilloscope.

In Fig. 5 such an FFT for $\omega_k/2\pi = 14$ MHz is shown. The central signal is given by the bunch frequency. At each side, two strong signals at 2.5 MHz could be seen already before any signal was applied on the kicker. This was associated with a modulation seen on the current signal at the exit of the first accelerating section and is thought to come from the non-uniform signal of the klystron.

The signal from the kicker could always be seen and, for $\omega_k/2\pi$ less than about 9 MHz, it was altered by the 2.5 MHz signal. The amplitude of the signal from the kicker varied only slightly with ω_k, so that we could not say with certitude if a high impedance HOM was excited or if this variation is due to the harmonics from the number of bunches (1 MHz). During the kicker frequency sweep, we looked in parallel at the spectra between 4.1 and 4.3 GHz from the first HOM couplers and for many frequencies at the first and sixth passbands as well. No mode was seen to be amplified in these frequency ranges.

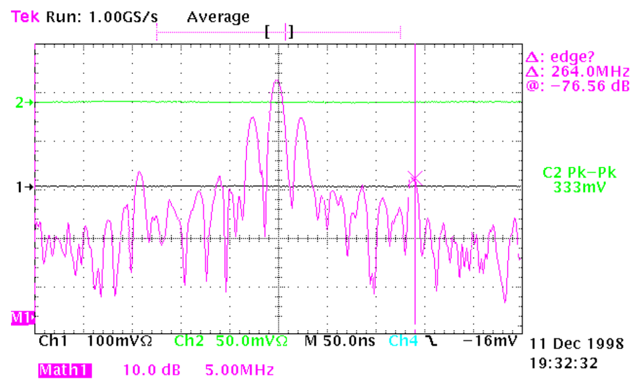

Figure 5: FFT of the BPM difference signal for a kicker modulation of 14 MHz

4 CONCLUSIONS

By using the beam, HOMs have been excited and viewed by means of HOM waveguide couplers. Some passbands could be distinguishes. The dipole character of the modes in the first passband was deduced. Based on the local coupling of the modes to the beam, the local offset of the structure was deduced. The amplification of the modes whose frequencies are at multiples of the bunch frequency has been observed when using a bunch train. In the kicker experiment, no resonant amplification of the beam offset due to HOMs could be observed.

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