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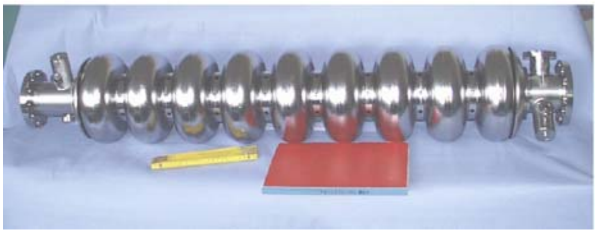

USING HIGHER ORDER MODES IN SUPERCONDUCTING ACCELERATING CAVITIES FOR BEAM MONITORING

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Abstract

Dipole modes have been shown to be successful diagnostics for the beam position in superconducting accelerating cavities at the Free Electron Laser in Hamburg (FLASH) facility at DESY. By help of downmixing electronics the signals from the two higher order mode (HOM) couplers mounted on each cavity are monitored. The calibration, based on singular value decomposition, is more complicated than in standard position monitors. Position like signals based on this calibration are currently being programmed in the control system. A second setup based on directly digitizing the spectrum from the HOM couplers has been used for monitoring monopole modes. The beam phase with respect to the RF has been thus measured. The position calibration measurements and phase monitoring made at FLASH are presented.

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Abstract

Dipole modes have been shown to be successful diagnostics for the beam position in superconducting accelerating cavities at the Free Electron Laser in Hamburg (FLASH) facility at DESY. By help of downmixing electronics the signals from the two higher order mode (HOM) couplers mounted on each cavity are monitored. The calibration, based on sigular value decomposition, is more complicated than in standard position monitors. Position like signals based on this calibration are currently being programmed in the control system. A second setup based on directly digitizing the spectrum from the HOM couplers has been used for monitoring monopole modes. The beam phase with respect to the RF has been thus measured. The position calibration measurements and phase monitoring made at FLASH are presented.

INTRODUCTION

RF accelerating cavities can support, apart from the accelerating mode, a multitude of resonant modes, the so-called higher order modes (HOM). These modes are excited by the charged particle beams and can lead to an increase of the beam emittance or even to beam break-up in large accelerators. However, the HOMs can be useful for beam diagnostics. The dipole modes have a linear dependency of their amplitude and phase with the beam offset and angle. Therefore they can be used for position monitoring [1], similarly to cavity beam position monitors (BPM). By measuring the phase of monopole modes excited by the beam with respect to the injected fundamental mode, one obtains the phase of the beam relative to the RF.

Electronics to monitor cavity dipole signals has been built and installed at the Free Electron Laser in Hamburg (FLASH) facility [2]. This facility delivers an intense FEL beam with wavelengths between about 32 and 13 nm and is also used as a test facility for the X-Ray Free Electron Laser (XFEL) [3] and the International Linear Collider (ILC) [4]. The linac is also known as the TESLA Test Facility – Phase 2 (TTF2). Each of five superconducting accelerating modules contains eight 9-cell 1m 1.3 GHz accelerating cavities (TESLA cavities). The total energy is typically between 450 and 700 MeV.

Two HOM couplers [5] are mounted at either end of the TESLA cavities, extracting the power from the beam excited modes in order to reduce their impact on the beam. From the spectrum of the accelerating cavities [6], the three passbands are of interest for our work: two dipole bands between about 1.6 and 1.9 GHz and a monopole band between 2.38 and 2.46 GHz. Narrow band electronics has been built for each of the 80 couplers enabling the on-line beam position monitoring. A broadband setup using two fast oscilloscopes can synchronously measure from several HOM couplers the spectrum up to about 5 GHz.

This paper presents first results from the recent measurements in August 2006. These measurements had as main purpose the calibration of the HOM signals into BPM-like signals and the integration in the control system. The calibration method is briefly described and preliminary results are presented. The phase of the beam with respect to the RF has also been investigated with the broadband setup and preliminary results are shown.

BEAM POSITION MEASUREMENT

Narrowband Electronics

For beam position monitoring, narrow-band electronics has been built and installed at each HOM coupler in FLASH. Its principle is shown in Fig. 1. A band pass filter selects a dipole mode around 1.7 GHz. This is then down-mixed to approximately 20 MHz IF and digitized. The local oscillator and the digitizer clock are produced as harmonics of the 9 MHz reference signal, which is used to produce the 1.3 GHz fundamental RF. A detailed description of the electronics can be found in [7].

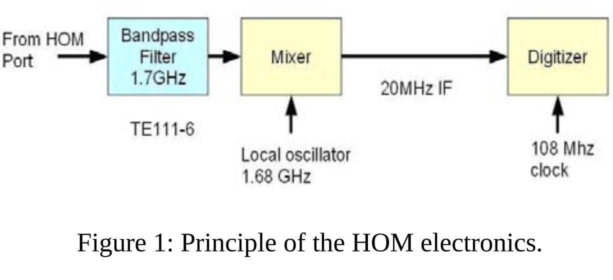

Figure 1: Principle of the HOM electronics.

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Fig. 2 shows an example of a raw output from one of the HOM electronics in time domain for a single bunch. Since each dipole mode has two polarizations with slightly different frequencies due to the asymmetries in the cavities, one can see in the waveform the beating between the two frequencies. The amplitude is decaying in time depending on the quality factor. For the first part of the signal the digitizers are saturated, due to a large beam offset.

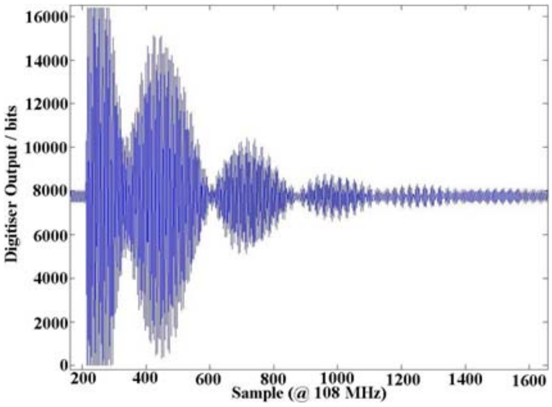

Figure 2: Example of single bunch raw signal from one HOM electronics. The horizontal axis unit is in 1/108 µs.

Calibration

In order to convert the HOM signals into beam position and angle, one needs to make a calibration. Fig. 3 shows the calibration setup. Two steering magnets are used to generate various beam trajectories for single bunch pulses through an accelerating module containing 8 cavities. The HOM signals are read simultaneously with the indications of two BPMs at either end of the module and the steerer settings.

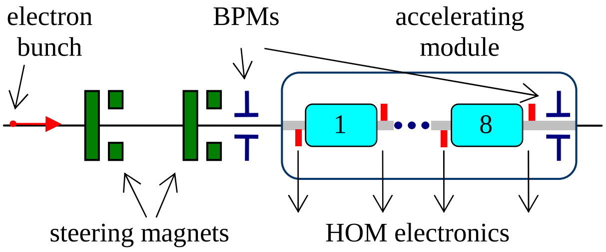

Figure 3: Calibration setup.

For calibration one predicts the beam position at the cavity of interest by interpolation of the readings of the conventional BPMs. This prediction is then associated with the HOM reading at that cavity.

Singular Value Decomposition

Since it is difficult to find the frequencies of the two polarizations of this mode by fitting the HOM spectrum, a different method has been chosen. We use Singular Value Decomposition (SVD) to find an orthonormal basis for the data set. The amplitudes of the strongest basis modes are used. The cavity modes are then combinations of these basis modes. Linear regression correlates then the amplitudes to the beam positions at the cavity location as predicted by the conventional BPMs [7, 8].

Calibration scans

A large number of scan steps, with various beam trajectories in the 4-dimensional space need to be taken. Collecting data from all HOM couplers for 100 points takes about 20 minutes, therefore the number of scan points has to be kept to a minimum. Previous calibration data used one dimensional scans in each of the 4 dimensions around a beam trajectory with roughly minimized HOM signals [7, 8]. In most cases, no measurement was near the axis of the mode, for which the mode was minimized in the 4-dimensional space.

In order to cover better the transverse space without increasing considerably the number of scan points, we decided to randomize fully the scans. We took for each module sets of 250 points. From these, calibration matrices were obtained.

Beam position measurement

First estimations of the resolution achieved with the new calibration in a few cavities showed values of 5-10 µm rms. Fig. 4 shows a histogram of the residual between the position reading at one cavity and the prediction of the beam position at that cavity from the position measured in the two adjacent cavities. A resolution of 5 µm is obtained in this case. Theoretically, a much better resolution is achievable. However, the data has still to be analyzed. A resolution of 1.5 µm has been previously observed [8].

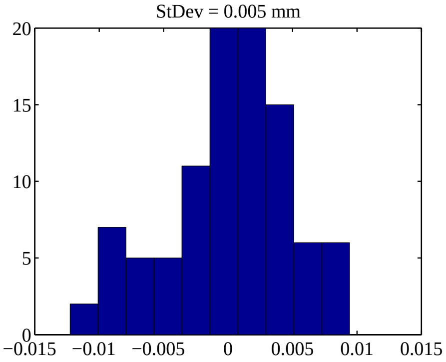

Figure 4: Histogram of the residual (in mm) of the beam position measured in one cavity against the prediction from the two adjacent cavities.

Preliminary integration of the HOM-BPM signals in the control system

The calibration matrices could already be used in the past for off-line beam position measurement tests. During the August studies parallel work has been made to integrate the beam position measurement into the control system of FLASH: the Distributed Object Oriented Control System (DOOCS) [9]. A server has been written for this purpose. Single bunch position signals from the HOM-BPMs have already been included in the control system. However this is very preliminary at this moment and the results have to be checked for consistency.

BEAM PHASE MEASUREMENT

Broadband Setup

A broadband system was used for monopole mode based beam phase measurements. This system directly digitized the signals from HOM couplers, without down converting, with two fast oscilloscopes (4 and respectively 6 GHz) [8]. The spectrum includes the 1.3 GHz accelerating mode leaking through the coupler and the first higher order monopole band around 2.4 GHz. The phase of the monopole modes can be measured precisely, defining a reference for the measurements of the phase of the 1.3 GHz signal. A windowing function is used to select the bunch for which the phase is estimated. The bunch spacing is currently typically 1 μs.

Phase measurement

The signals from one HOM coupler per module have been monitored. The five signals could be displayed and analyzed in parallel. Figure 5 shows a controlled 10deg phase change commanded at the klystron feeding one module with RF. The resolution observed so far is about 0.1 degrees. This could be increased for single bunch by using a longer window.

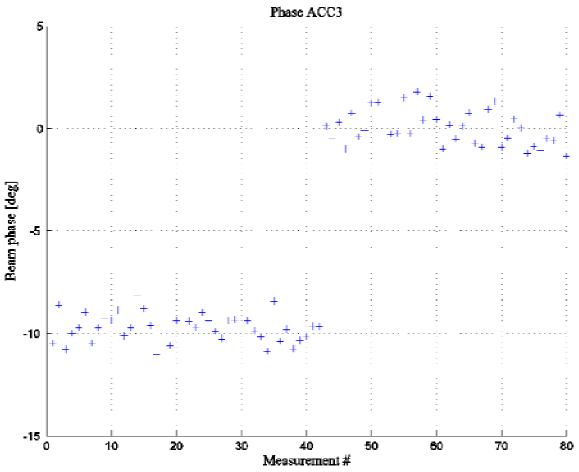

Figure 5: 10 deg phase change of the 1.3 GHz RF signal, measured with the HOM signals.

COMMENTS AND OUTLOOK

The results from the recent HOM measurements presented in this paper are preliminary. The data collected has to be analyzed and the integration of the HOM-BPM signals into the control system has to be checked.

The calibration procedure at this time depends on the accuracy of the calibration of the BPMs. Also the procedure is at this time lengthy. Efforts are on-going to have a calibration procedure for all the accelerating modules at the same time.

The possibility to measure the beam position from the cavities has the potential of precise measurements of 1 μm resolution or better. This could mean reducing the number of conventional BPMs installed in the long linacs of the XFEL and the ILC, or at least relaxing the requirements and the costs of these BPMs.

The narrowband as well as the broadband setup have other applications than the beam position and phase monitoring. The narrow band electronics has been used for measuring the cavity alignment in the cryo-modules [8]. Also successful feedback tests have been made, to bring the beam position where the HOM signals are at a minimum in a given module. In this way one should minimize the effects of the long range wake fields on the beam.

The broadband data collected can be used for measuring the relative alignment of the axes of various dipole modes, thus having the potential of obtaining information on the cavity geometry.

An alternative setup for beam position measuring with the HOM signals based on an FPGA board has been tested, and is being programmed.

Single bunch position monitoring should also be tested in multi-bunch mode. This is possible due to the knowledge of the modes properties, thus the contribution to the HOM signal from previous bunches can be subtracted.

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