COMMISSIONING OF THE ELECTRONICS FOR HOM-BASED BEAM DIAGNOSTICS AT THE 3.9 GHz ACCELERATING MODULE AT FLASH*

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Abstract

Transverse Higher Order Modes (HOM) excited by electron beams in the 3.9 GHz accelerating cavities at FLASH may damage the beam quality. They can be reduced by extracting their energy through special couplers and by aligning the beam in the cavity. Electronics has been designed at FNAL for monitoring some of the potentially most damaging HOMs. This may be used for beam centering and therefore reducing the HOM effects. Moreover, the signals can be potentially calibrated into beam offset, so that they could be used as beam position monitors (HOM-BPM). The specifications of the monitors have been defined during an extensive study on the 4-cavity accelerating module installed at FLASH. Signals around 5.46 GHz have been chosen for higher precision measurements. However these signals propagate into the entire 1.2 m long module. Therefore in addition modes at about 9.06 GHz were selected for localized measurements in each cavity. The electronics has been recently installed at FLASH. The initial experience with this electronics is presented in this paper. The signals can already be used for centering. Some instability in the signals has been observed and the cause has to be further investigated.

INTRODUCTION

Higher Order Modes (HOM) excited by electron beams when traversing accelerating cavities can be used for beam alignment [1]. This is beneficial to the beam quality since in this way the transverse HOMs are reduced and therefore also their potentially damaging effect on the beam. HOMs can also be used as beam position monitors (BPM), similar to cavity BPMs. In particular dipole modes are very suitable due to the linear dependence of their strength on the beam offset.

The principle has been demonstrated in the past at the FLASH linac at DESY, Hamburg [1,2], using special HOM-BPM electronics built at SLAC and installed at forty 1.3 GHz cavities. One issue remains, namely that the calibration is instable [3]. However this affects only the functioning as a BPM, the raw HOM signals are used to align the beam.

Recently, electronics has been built at FNAL for the four 3.9 GHz cavities at FLASH. This paper presents the first beam experience with this electronics at FLASH. The challenges in comparison to the one for the 1.3 GHz cavities will be underlined.

The FLASH Injector

Figure 1 shows schematically the injector of the FLASH linac [2]. The electron bunches produced by the photo-gun pass the first accelerating module (ACC1), containing eight 1.3 GHz cavities, and then the third harmonic module (ACC39), containing four 3.9 GHz cavities, before going through the first bunch compressor. The 3.9 GHz cavities are used to linearize the energy spread along the bunch needed in the compression process. Magnets and beam monitors, such as charge, position and phase monitors are not shown.

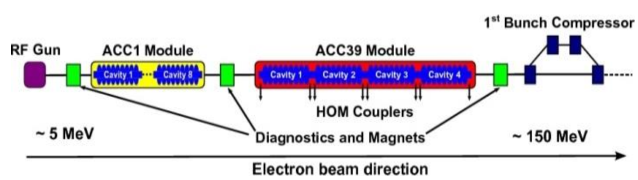

Figure 1: Layout of the FLASH injector. (The accelerating cavities are not to scale: the 3.9 GHz cavities are about 3 times smaller than the 1.3 GHz ones.)

The Third Harmonic Module

The arrangement of the 3.9 GHz cavities in ACC39 is shown in Figure 2. Each cavity has a power coupler and two couplers for HOM-damping. Two of the cavities, C1 and C3, are oriented with the power coupler downstream, the others have it upstream. The HOM-couplers are named with the cavity (C) and coupler (H) number, with H1 being on the power coupler side.

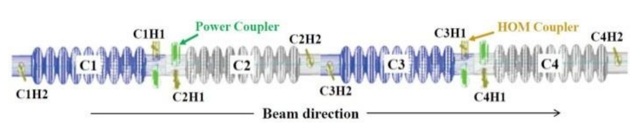

Figure 2: The arrangement of the 3.9 GHz cavities in the ACC39 cryo-module.

The HOMs in the 3.9 GHz cavities are much stronger than in the 1.3 GHz cavities due to the smaller aperture. This makes the need to align the beam in the cavities, and therefore avoid exciting transverse modes, more important. This is also the main reason why the beam pipes are larger than 1/3 of the beam pipes for 1.3 GHz cavities. This allows most modes to propagate along the entire module, and be damped by all couplers. On the

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other hand, this makes the spectrum much more crowded so that basically no isolated HOM can be filtered out. Also, with propagating modes one cannot measure the beam locally in each cavity, as it is done for the 1.3 GHz cavities. However modes in a narrow frequency range around 9.06 GHz, in the 5th dipole band, are trapped in the cavity, as a previous study with test electronics has found [4,5]. These modes can be used for alignment of the beam and position measurements in each cavity, at the expense of a lower resolution. For a measurement with a higher precision, the most suitable proved to be propagating modes around 5.5 GHz, in the 2nd dipole band.

HOM-BPM DOWNMIX ELECTRONICS

Downmix electronics shown in Figure 3 have been built to study modes of interest in 2nd and 5th dipole bands. The electronics consist of one 5 GHz PLL and one 9 GHz PLL each of which are locked to a FLASH low level RF 81MHz reference and programmable in 9 MHz steps over a 100 MHz range in each pass band. There are three 5 GHz and seven 9 GHz downmix. 1 of each is connected to a phase monitor pickup to allow an independent beam measurement of the system phase. The system can be configured remotely via a CAN Bus serial interface.

Figure 3: Front of the HOM-BPM electronics.

The block diagram for a downmix channel is shown in Figure 4. Each channel has a 100 MHz BW input filter centered on the band of interest. As the characteristics for each HOM coupler vary, there are programmable attenuators before the mixer to optimize the signal levels into the mixer. The mixer is a single sideband mixer with an IF of 30 MHz with 20 MHz bandwidth. For the beam commissioning, the LO frequencies are set to 9.027 GHz and 5.434 GHz to select HOMs around 9.058 GHz, and respectively 5.465 GHz.

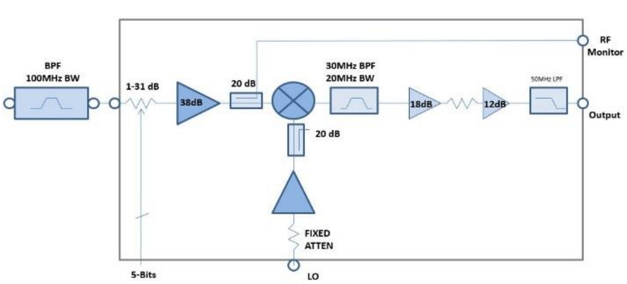

Figure 4: Block diagram of a downmix channel.

BEAM MEASUREMENTS

The HOM-BPM electronics has recently been installed at FLASH. The downmixed signals are send to a SIS8300 digitizer card via a SIS8900 card [6] placed in a MTCA crate [7]. A so-called scope server was installed to transfer the digitized signals from the SIS8300 card to the control system [8]. The sampling rate of the digitizer is 108 MHz. After adjusting the LO and the attenuation level for each channel, signals could be readily observed. Examples of 5 and 9 GHz signals are shown in Figure 5. Such signals can be already be used for beam alignment.

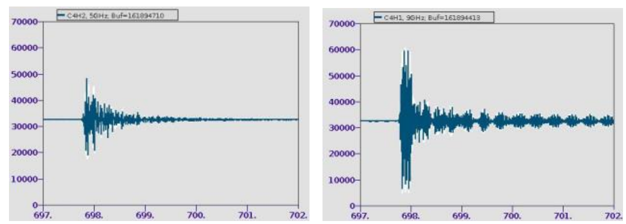

Figure 5: Raw signals from C1H2 (5 GHz channel) and C1H1 (9 GHz) from the control system.

During a dedicated beam time, the behavior of the signals with the transverse beam position has been studied. Two BPMs, one upstream and one downstream ACC39 have been used for beam position reference. The RF in the module has been switched off, while the quadrupoles have been cycled to zero field. In this way a drift space was created between the BPMs.

While placing the beam at various transverse positions in a somewhat equidistant grid, the signals from all channels of the HOM electronics have been recorded synchronously to the beam charge, position and phase readings. 5 pulses have been read for each position. One scan with 25 beam positions has been made first and the data was used for signal calibration. A second scan, with 16 positions within a smaller range is used for characterization of the system (validation data).

Figure 6 shows the beam position interpolated at the module center. A range of roughly 0.25 mm in the x plane and ±3.5 mm in y was covered. The strong difference is that with the used steerer magnets a divergent trajectory in y was obtained, while in x the beam was crossing the axis in ACC39. The x range was larger at the outmost cavities.

Figure 7 shows the waveforms obtained for all 25 beam position in the calibration scan from both 5 GHz channels (a), and the corresponding spectra obtained by Fourier transforms (b). One notices the variation in amplitude of the various modes with the beam position.

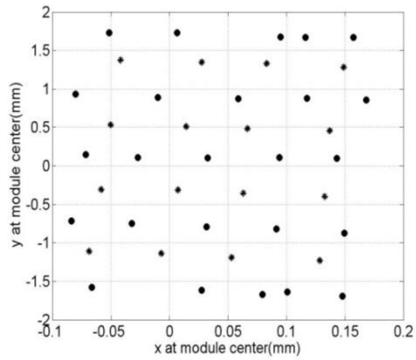

Figure 6: The beam positions as calculated at the module center from the two BPMs. One (larger) scan has been made for calibration data (dots), and another for validation data (stars).

The most relevant information from the HOM data has been extracted with a SVD-based technique [1,4]. By linear correlation against the beam position a matrix has been obtained for calibration of the HOM signals into beam position.

The RMS error obtained by applying this calibration matrix to the data used for obtaining it is a first indicator on how good the data is, and if the electronics behaves as expected. Another RMS error is obtained when applying this matrix to the validation data. Note that this RMS error is not the resolution of the HOM electronics, since it is obtained for a large beam position range.

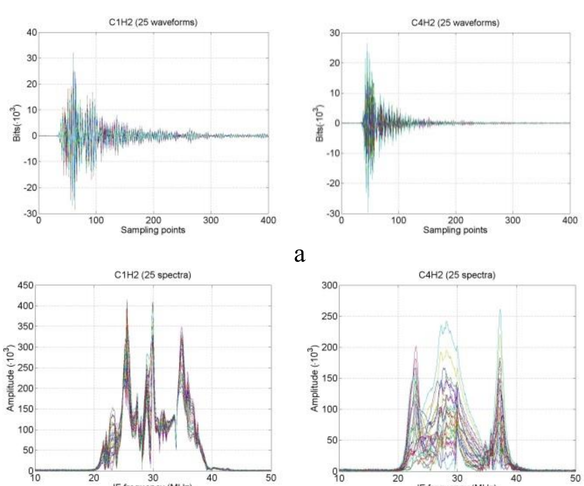

Figure 7: Waveforms (a) measured from the 5 GHz channels (C1H2 and C42H2) and the corresponding HOM spectra (b) obtained by Fourier transform.

Similarly, Figure 8 shows the waveforms from three of the 9 GHz channels (a) and their corresponding spectra (b). Note that the waveforms and spectra vary dramatically from coupler to coupler, due to the fabrication differences and different couplers.

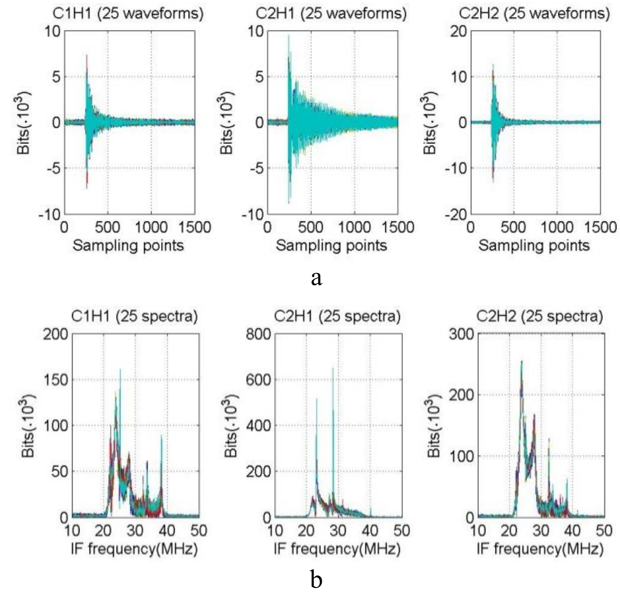

Figure 8: Waveforms (a) measured from three 9 GHz channels (C1H1, C2H1 and C2H2) and the corresponding HOM spectra (b) obtained by Fourier transform.

Figure 9 shows the beam position in the middle of the module as calculated from the BPM readings (blue) and as obtained from the calibration of the HOM signals (red). The two waveforms from the 5 GHz channels (see Figure 7) have been concatenated. The dots for each beam pulse are connected with each other. The RMS error obtained for the calibration data is 12 µm for x and 41 µm for y. Similar values are obtained for the validation data. The results are in agreement to the expected values (below 50 µm) from previous studies [4,5]. The y values are larger due to the large scan range. Similar values are obtained when using the signals from each coupler individually.

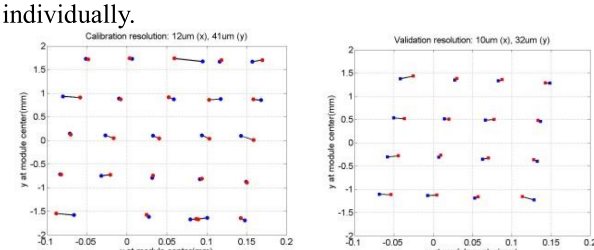

Figure 9: RMS errors obtained from calibration (left) and validation (right) data for the concatenated 5 GHz channels. Each beam position as interpolated from the BPMs (blue) is connected to the resulting position from the HOM signals (red).

Values below 100 µm are expected for each 9 GHz channel. However we obtain values between 20 and hundreds of µm rms. Table 1 summarizes the results for the 9 GHz channels. For cavities 2 and 3 also the results with concatenated waveforms are shown.

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Table 1 RMS Error Obtained for the 9 GHz Channels

	Calibration Data		Validation Data	
Channel	**x [µm]**	**y [µm]**	**x [µm]**	**y [µm]**
C1H1	21	104	23	124
C2H1	31	649	27	435
C2H2	22	103	17	98
C2	*10*	*59*	*12*	*89*
C3H2	35	196	55	123
C3H1	16	164	35	79
C3	*13*	*260*	*25*	*118*
C4H1	46	131	46	116

The RMS errors obtained for the x plane are all very good, below 50 µm, but mostly above 100 µm for y. This cannot be all explained by the larger scan range, since such scans have been used before with good results [4]. Some instability of the signal has been observed sometimes in some of the channels, and this may be the reason for the bad results. In different beam scans even higher values also for the x plane were obtained. Further investigations are necessary before continuing with the work.

CONCLUSIONS AND OUTLOOK

Downmix electronics has been designed and installed at all four 3.9 GHz cavities at FLASH. Dipole modes at 9058±10 MHz are used for beam alignment and position measurement in each cavity, while modes at 5465±10 MHz are used for more precise measurements. The best RMS error obtained so far by moving the beam in a relatively wide range is of the order of 12 and 40 µm (x and y planes) for 5 GHz modes. For the 9 GHz channels the error is below 50 µm for the x plane and above 100 µm in the y plane. It is not yet clear why we cannot reproduce the results with the test electronics, particularly for the 9 GHz channels. Investigations on the stability of the signals in the HOM-BPMs electronics are planned. However the raw signals can already be used for beam alignment.

This electronics serve also as a prototype for the electronics developed for the 3.9 GHz cavities at the European XFEL [9].

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