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INVESTIGATIONS OF THE WIDEBAND SPECTRUM OF HIGHER ORDER MODES MEASURED ON TESLA-STYLE CAVITIES AT THE FLASH LINAC[*]

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Abstract

Higher Order Modes (HOMs) excited by the passage of the beam through an accelerating cavity depend on the properties of both the cavity and the beam. It is possible, therefore, to draw conclusions on the inner geometry of the cavities based on observations of the properties of the HOM spectrum. A data acquisition system based on two 20 GS/s, 6 GHz scopes has been set up at the FLASH facility, DESY, in order to measure a significant fraction of the HOM spectrum predicted to be generated by the TESLA cavities used for the acceleration of its beam. The HOMs from a particular cavity at FLASH were measured under a range of known beam conditions. The dipole modes have been identified in the data. 3D simulations of different manufacturing errors have been made, and it has been shown that these simulations can predict the measured modes.

INTRODUCTION

An electron beam moving through a superconducting accelerating cavity will produce an electromagnetic ‘wake’. Short range fields produced by the head of the bunch may act on the tail, thereby degrading the quality of the beam, and longer range fields may act on subsequent bunches in a way that reduces their quality. In the worst case, these fields may be resonant with the inter-bunch spacing, causing beam blow up (BBU).

The wake fields can be expanded as a multipole series, and, due to the cyclindrical symmetry of the accelerating cavities, each term in this series may be classified according to its azimuthal symmetry as being monopole, dipole, quadrupole, or higher order in nature. Each of these terms is known as a higher order mode (HOM). It is important to note that each dipole mode will exist in two orthogonal polarisations, and that the degree of frequency splitting of these modes is related to ‘asymmetries’ in the cavity design, e.g. manufacturing errors, and the presence of RF couplers at various points along the cavity.

Since HOMs are potentially damaging to the quality of the beam, their effect is reduced by careful design of the cavity geometry, and by inclusion of HOM coupler ports. These are designed as wideband devices to extract the power of the HOMs, but with a tunable bandstop filter to minimise the coupling to the accelerating mode. By monitoring the output from these ports, it is, therefore, possible to monitor any modes generated by the beam that couple well to them.

This paper describes a wideband measurement of the HOM signal induced by the beam in a superconducting cavity at FLASH [1], DESY. The spectrum of this signal is analysed in order to isolate the dipole modes. Their frequencies are measured and compared with those predicted from computer simulations.

FLASH FACILITY

FLASH is a free electron laser (FEL) facility at DESY. Electron bunches are accelerated to energies between 450 and 700 MeV, compressed to form a ∼50 fs spike of charge. During its passage through a subsequent undulator section, this spike generates a beam of photons with wavelengths of between 32 and 13 nm through the process of self-amplified spontaneous emission (SASE).

During the experimental run described in this paper, the acceleration took place in five TESLA–style, cryogenic modules, each of which contained eight superconducting accelerating structures. A schematic of the facility is shown in figure 1. Each accelerating structure contains two HOM couplers (one upstream and one downstream rotated azimuthally by 115°), so eighty signals are available for monitoring.

DATA COLLECTION

Due to the necessity of removal of the HOM power, beamline hardware already existed for this purpose, therefore installation of beamline hardware for this experiment was unecessary. The HOM power, instead of being dissipated in a load, was fed into electronics designed for an experiment to extract the beam position from the HOM modes [2]. These electronics included a 14 dB coupler on the input that allows monitoring of the raw input signal (i.e. a reduced power version of the HOM port output). This system inevitably leads to contamination of the recorded

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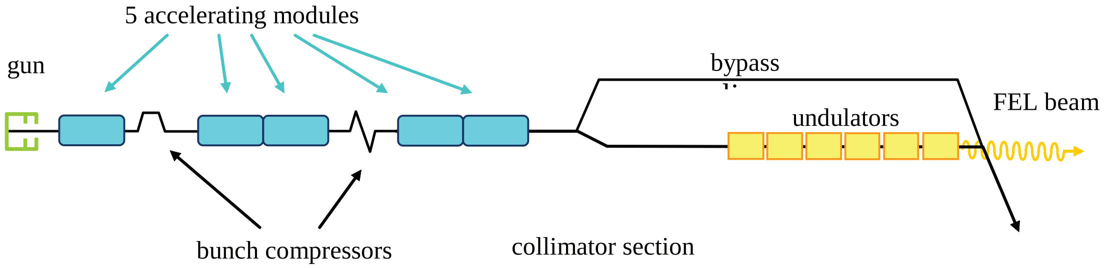

Figure 1: Schematic of the FLASH facility.

signal with artifacts from the beam position electronics.

The output signal was then recorded on a scope with a sampling rate of 20 GS/s and a bandwidth of 6 GHz. Since two such scopes were available, it was possible to utilise only one channel of each to measure the up- and downstream couplers of one cavity, thereby allowing the full sampling rate of the scopes to be achieved.

Simulations showing the presence of a strong dipole mode at ∼1.7 GHz have been confirmed by subsequent measurements of each of the FLASH cavities [3]. These measurements also indicated the size of the splitting of the two polarisations of this mode, and it was noted that this splitting was largest in the case of the fourth cavity in the fourth accelerating module (∼0.8 MHz). Since this is most likely related to cell deformations due to cavity mannufacturing errors, this cavity was chosen for the measurements in order to measure the magnitude of the deviation from the simulated results.

DATA ANALYSIS

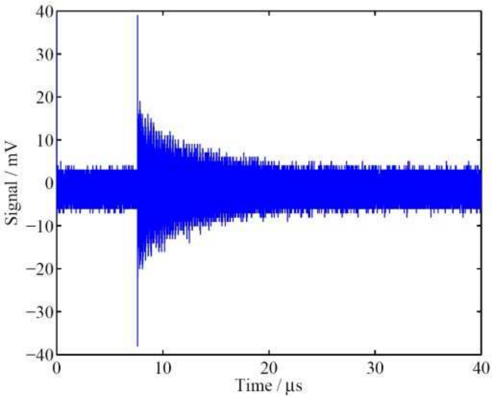

Figure 2: Example of a recorded HOM signal.

Figure 2 shows an example of a recorded waveform, and figure 3 shows the average power spectrum for 36 beam pulses. Many lines can be seen in this spectrum, most of which are scope artifacts and other spurious signals. The HOM signals must be extracted from this in order to analyse them.

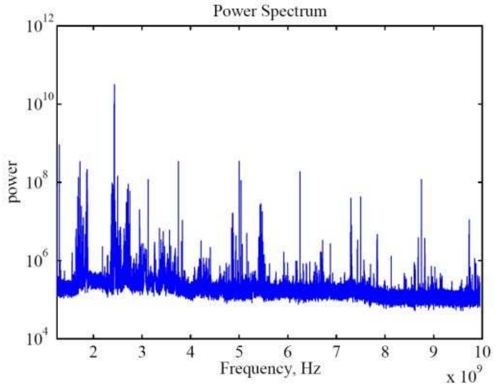

Figure 3: Average power spectrum of the HOM output for a dataset of 36 beam pulses.

Locating Dipole Modes

It may be assumed that if the power present at a particular frequency has a strong correlation with the position of the beam, then this signal must be a dipole mode. For each frequency in the spectrum, a regression analysis was used to find the correlation of the complex amplitude in that band with the position of the beam as interpolated from beam position monitors (BPMs). This correlation can then be used to predict the beam position from the complex amplitudes at different frequencies, and a ‘resolution’ or ‘fit error’ can be determined for that frequency by comparison with the beam position predicted from the BPMs.

Frequency Measurement

Figure 4 shows the results of the dipole mode location process. It is a plot of the ratio of the error of the beam position prediction to the total variation of the position (i.e. a perfect correlation will give a ratio of zero, while a ratio of unity implies there is no correlation at all). A black horizontal line has been plotted to show the ratio below which it is possible to identify modes cleanly. Unfortunately it was not possible to cleanly identify the properties of the bands visible at ∼2.6 GHz and ∼3.1 GHz due to their low amplitude.

Figure 4 shows that there are no measureable dipole modes above ∼3.1 GHz. This agrees with simulations of the cavities [4] that predict only modes with a low R/Q

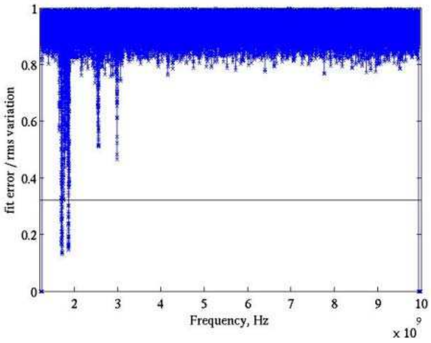

Figure 4: Dipole mode identification: Ratio of fit error to the total variation. The black line is an indication of the cut-off point of the dipole mode search algorithm.

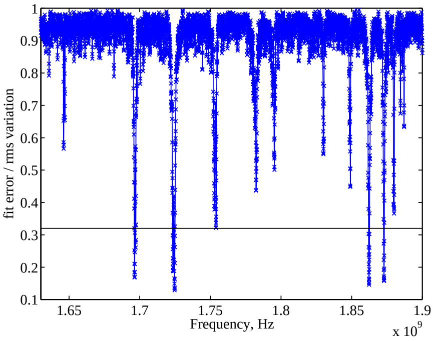

Figure 5: Dipole mode identification: Magnification of the area of the first and second dipole bands.

above this frequency. Figure 5 is a magnification of the 1.6–1.9 GHz region to show the first and second dipole passbands (see [4]). The measured centre frequencies of the four modes with fit ratios that cross the cut indicated in figure 4 are shown in table 1 alongside 3D prediction of the cavity simulations [5].

Figure 6 is the same plot as figure 4, but zoomed into the 1-6 mode from table 1. The ~0.8 MHz splitting of this mode can be seen quite clearly.

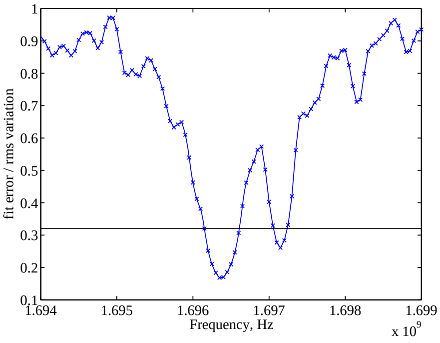

Figure 6: Dipole mode identification: Magnification of the area of the strong mode at ~1.7 GHz.

Table 1: Centre frequencies of four strong dipole modes.

Band - Mode	**Predicted Freq. / GHz**	**Measured Freq. / GHz**
1 - 6	1.7060	1.6964
1 - 7	1.7335	1.7236
2 - 3	1.8658	1.8623
2 - 4	1.8749	1.8729

Table 1 shows that, in this cavity, the frequency of the two measured modes in the first dipole band have been shifted downwards by ~10 MHz with respect to the frequencies predicted by a 3D simulation, while the measured modes in the second dipole band have only small downward shifts. These numbers are consistent with the shifts predicted in simulations of cavities with manufacturing imperfections [6].

CONCLUSIONS

It has been shown how beam based measurements of the HOM signals can locate high R/Q dipole mode signals by correlating the complex amplitude of the signal at each frequency in the fourier transform with the position of the beam. The modes found using this method can be mapped on to the predictions of 3D simulations of these cavities, and 3D simulations of cavities with reasonable manufacturing errors can be made to agree with the measured frequencies.

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