OPTIMIZATION OF BEAM INJECTION INTO THE FIRST ACCELERATING MODULE AT TTF WITH CAVITY DIPOLE MODE SIGNALS

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Abstract

The TESLA Test Facility (TTF) is a user facility for intense VUV-FEL light. The facility is densely equipped with diagnostics, essential in obtaining the necessary beam parameters, in particular the low emittance. However there is no dedicated component for alignment of the beam in the accelerating modules, each containing eight superconducting cavities. Large beam offsets can lead to an increase of the beam emittance. The centering of the beam in these modules is therefore important, mostly at the low energy end. A misalignment of the first TTF module with respect to the gun axis has already been observed using cavity dipole modes. This paper presents the experimental results of the optimization of the beam injection into the first module, based on the monitoring of dipole modes through the couplers installed for wakefield damping. For this we use a spectrum analyzer together with a multiplexer. By scanning the beam position and tilt with two pairs of steerers, we can find the trajectory which minimizes the dipole modes amplitude. The impact of the beam steering in the module on the beam is discussed. A time domain setup is also being presented.

INTRODUCTION

The TESLA Test Facility linac (TTF) at DESY serves as a user facility for intense VUV-FEL light [1]. Each of the five TESLA cryo-modules contains eight 9-cell superconducting cavities, which accelerate the electron beam generated by a photo-cathode to about 450 MeV. Transverse higher-order modes (HOM), resonant fields excited in the cavities by off-axis charged particles, can give kicks on the subsequent beam, leading to emittance growth of the pulse train. In particular, at low energies the effect can be significant. Dipole modes are of main concern. The modes of individual cells are degenerated into 9 modes grouped into passbands.

Although there are various monitors for beam diagnostics in the facility, there is no dedicated device for beam alignment in the modules. Signals suitable for beam alignment are however available, from the HOM couplers with which each cavity is equipped [2]. These couplers extract energy from the HOM, particularly the first two dipole passbands, where most modes with highest impedance can be found. The amplitude of the resonant fields is proportional to the beam offset with respect to the cavity axis and to the bunch charge. Each dipole mode is split into two modes, with different polarizations. The axes of the two polarizations are orthogonal to each other for a circularly symmetrical structure.

From the coupler, the modal energy is normally brought through long coaxial cables to loads. We have disconnected the loads and monitored the amplitude of each mode with a spectrum analyzer. With a multiplexer we are able to choose one coupler out of 16 present in each module, as shown in Fig. 1. Therefore we can monitor the beam position in each cavity individually.

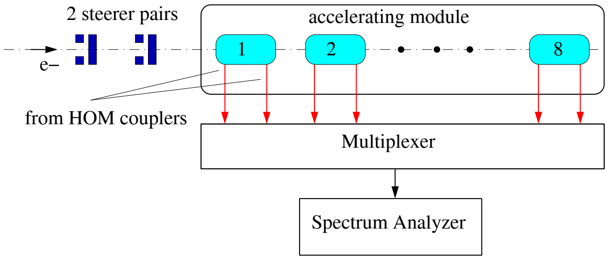

Figure 1: HOM setup for frequency domain measurements

In the next section we describe the procedure used for the alignment on the axis of the first cavity of the first TTF accelerating module. The results are compared to results from studies on beam properties. In the following section a time-domain recorder system is presented, which has recently been installed at TTF. Measurements made with this system are mentioned. There are four modes with high loss factors in the first two dipole bands, which makes them most suited for monitoring[1]. In this paper we have used modes 6 and 7 from the first band, at about 1710 MHz and 1730 MHz.

BEAM ALIGNMENT IN ACC1

The purpose of the measurements was to align the beam on the axis of cavity 1 of the first accelerating module, denoted by ACC1. The beam alignment is most critical here since kicks on the beam are highest due to the low energy of 4.6 MeV given by the gun. We chose mode number 6 from the first dipole passband, with $R/Q = 11$ MΩ/m^2. The

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[1] A strong mode in the third passband is not suited, since it is very close to other modes.

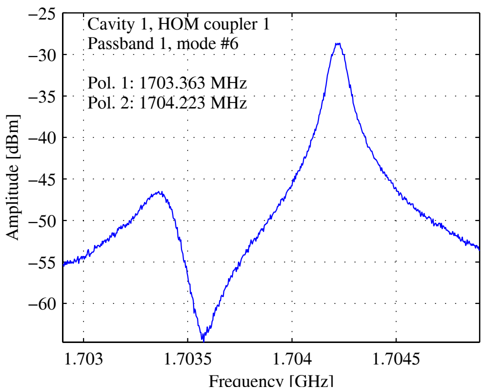

Figure 2: Spectrum of mode nr. 6 from the first dipole passband of cavity 1, ACC1.

two polarizations have in this cavity frequencies of $f_1 = 1703.4$ MHz and $f_2 = 1704.2$ MHz. They can be seen in the spectrum shown in Fig. 2. The split in frequency is caused by the asymmetries in the cavity.

In order to find the center of the cavity, we have moved the beam transversely with steerer pairs such that the angle of the beam in the middle of the cavity is constant. The position of the beam has been scanned. The amplitude of the dipole mode has been recorded. Mode f_2 has proved to respond to horizontal beam movement, while f_1 is sensitive to vertical position [3]. Since it takes a long time to get a spectrum due to the pulse repetitions frequency of 2 Hz, we measure the dipole mode in time domain. A single bunch per train with 1 nC charge has been used.

First a horizontal scan has been made (see Fig. 3-a). The horizontal axis shows the beam position in the middle of the cavity with respect to the starting position for the scan ($x = 0$ mm). A minimum of the amplitude of mode f_2 is seen at -2.7 mm relative position. The beam injection is set to this position and a vertical scan is next made while measuring the amplitude of mode f_1 (Fig. 3-b). The minimum is observed at about the initial beam position. In this way the center of the cavity is localized.

Next, by keeping the beam position constant, we varied its angle to find the cavity axis. The horizontal scan is shown in Fig. 3-c. The minimum dipole amplitude is found at about -90 μrad. A vertical scan (Fig. 3-d) of the beam angle around this position shows an already good alignment in this plane. The beam is now aligned on the axis of the first cavity of the module.

Results and discussion

Time only allowed for measurements to be made in cavity 1. The lowest wakefield effects on the beam from the whole module are expected to be different from this results. However, bringing the bunches on the axis of cavity 1 should provide a good first order alignment in the accelerating module.

Later, studies were made on the steering of the beam generated by module ACC1. The gradient of the accelerating field has been changed and the variation of the beam position has been studied. The injection conditions have been found for which the change in transverse beam position downstream of the module is minimum. The achieved injection was close to the position found with the HOM signals in the horizontal plane: the beam position and angle at the entrance of cavity 1 were within 10 μm and respectively 10 μrad. In the vertical plane the beam injection into the module differed by 0.8 mm and respectively 1.3 mrad.

It has to be mentioned that the beam position after passing an accelerating module is affected by the combined effect of wakefields, coupler kicks, cavity tilt and focusing. No change in deflection while varying the accelerating gradient means that the sum of all these effects cancel at the exit of the module, which does not necessarily match an on-axis beam in cavity 1.

The comparison of the steering study to the HOM beam alignment in cavity 1 seem to indicate a tilt of the cavity with respect to the module axis in the vertical plane, but a good horizontal alignment. This has to be confirmed in the future, by monitoring the HOM amplitude in more than one cavity.

A simple method, is to align the beam through the center of the first and last cavities. Moving the steerers such that the beam angle in the center of the first cavity stays constant, and finding the position for which the amplitude of an excited dipole mode is minimum, brings the beam through the center of the cavity. Starting from here and changing the beam angle such that the position in the middle of the same cavity is kept constant, the mode amplitude is monitored in the last cavity. The minimum will indicate that the beam goes through the middle of that last cavity. A

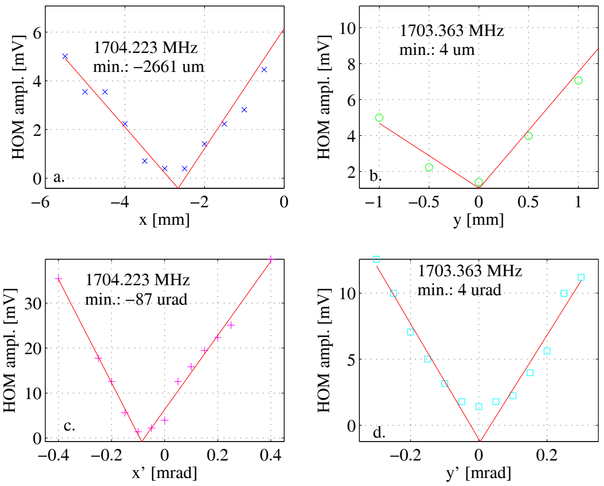

Figure 3: HOM amplitude with the change in beam position and angle in the middle of cavity 1, ACC1: a. horizontal position scan, b. vertical position scan, c. horizontal angle scan, d. vertical position scan. For each scan the position with minimum HOM amplitude from the previous scan is used as reference.

more complex alignment method implies the measurement of the HOM signals from all cavities and minimizing the overall wakefields.

TIME DOMAIN ELECTRONICS

While the frequency domain setup used for the above study is easy and straightforward, it has the disadvantage of being slow and of not providing the phase information. A special electronics has meanwhile been built, as shown in Fig. 4 [4]. The signal from a coupler is filtered around 1750 MHz, i.e. near the frequency of the 7th dipole mode in the first passband with $R/Q = 15.5$ MΩ/m^2. A 1.3 GHz reference signal is used to down-mix the signal, such that it can be displayed with a fast oscilloscope. A 9 MHz signal is used for time reference.

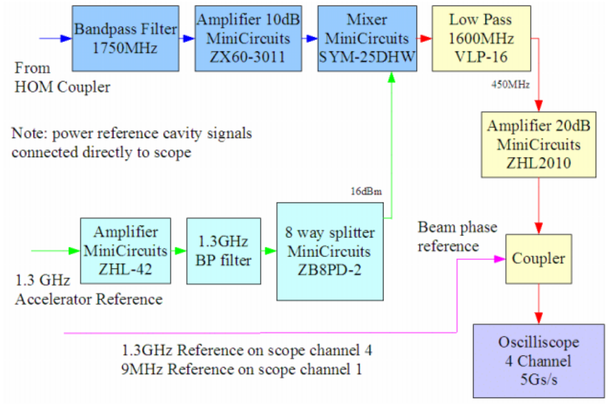

Figure 4: Block diagram of the down-mix electronics

This setup has the potential of measuring both beam offsets and angles with respect to each cavity axis. A calibration has to be made by moving the beam with steerers.

With one oscilloscope, four signals can be recorded in parallel, e.g. from the two couplers of two cavities. Measurements have been made in the fourth TTF module, ACC4. Single bunch beams have been used. The beam has been moved by a pair of correctors for each transverse plane. For more details on the measurement method see [4]. The resolution for beam position monitoring has been estimated to about 3 μm for a single cavity. Theoretically the achievable resolution is under 1 μm.

FUTURE PLANS

A system capable of monitoring simultaneously one or two modes from all 40 HOM couplers at TTF is being planned. The signals will be down-mixed to about 30 MHz and then digitized and send to the TTF control system. With this system a position resolution of better than 2 μm is expected.

Apart from using the HOM signals for beam position monitoring and alignment, the time domain and frequency domain setups are useful for other studies as well:

- The misalignment of the cavities in the modules have been measured at room temperature. The HOM setup can measure the cavity misalignment in the cold modules, providing for a cross-check of the mechanical measurements and cooling models.
- It has been observed that the center of a cavity differs for various dipole mode monitored [3]. A more thorough study of this and its implications is planned.
- The polarization of the dipole modes is not identical for all cavities. The direction of a mode depends on the ellipticity and misalignment of the cells in the cavity. Again a more detailed examination is necessary.

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