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Wake field monitoring to improve FEL performance

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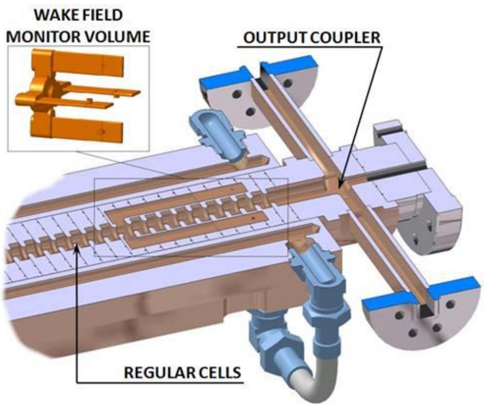
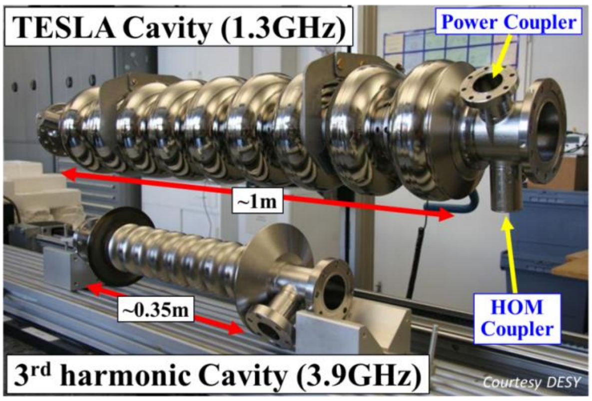
Beam degradation due to RF structure misalignments poses a challenge in the operation of ultra high brightness FELs. Wake field monitors offer a direct way to diagnose and correct these effects.



Down stream end of X band structure with wake field monitor pickup (Image credit: PSI)



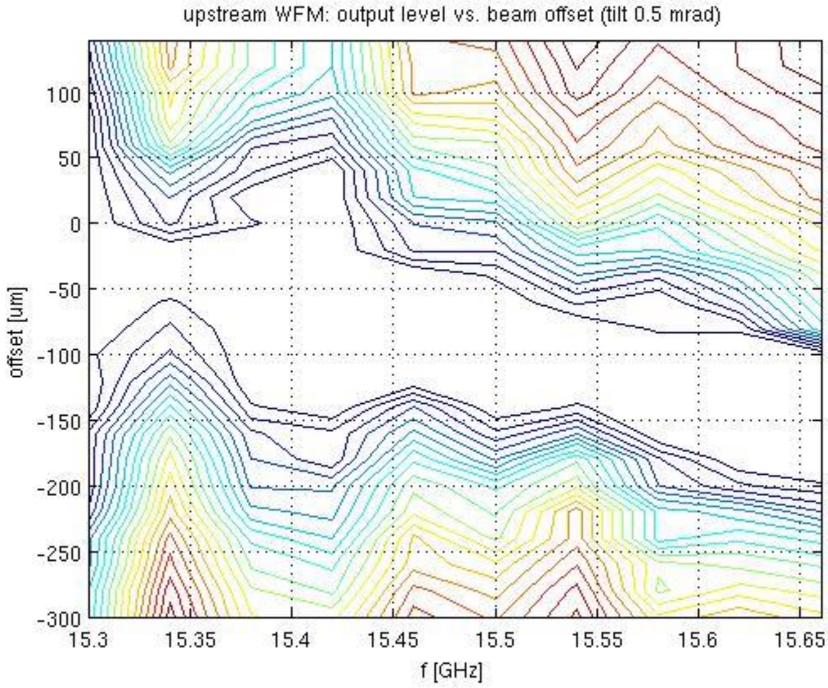
Superconducting accelerating cavities (Image credit: DESY)

The strength of the transverse wake fields, causing degradation of the beam quality, excited by electron beams inside RF accelerating structures increases with the offset between structure and beam. Wake field monitors (WFMs) are devices which couple to these fields and their components, the Higher Order Modes (HOM), and therefore enable their reduction. This is of special interest in the modern free electron lasers where the beam quality is of extreme concern.

Two teams from EuCARD2 **Work Package 12** explore this field, one developing a front end for the WFMs of a 12 GHz RF structure used for the **SwissFEL** and the other dealing with 1.3 and 3.9 GHz superconducting cavities of the **European X-ray Free Electron Laser (E-XFEL)**.

The X band linearizer structure used at SwissFEL, which have integrated wake field monitors, were produced in collaboration with CERN and Sincrotrone Trieste. They are 72 cells traveling wave structures with a phase advance of 5π/6. Two wake field monitors (shown in the title figure) selectively couple to the transverse HOMs up and downstream, while effectively suppressing the MW level fundamental mode power by a factor better than 100 dB. Their principal resolution is given by the internal precision of the structure assembly and should be in single digit micron range.

The WFM emits a broadband signal centered in the 16 GHz region. For a suitable front end to develop (done under EuCARD2), we use electro-optical conversion, transport, and down mixing of the signal, offering highly attractive features: Electro-optical techniques are already heavily used in space communication, suitable components with high bandwidths up to 40 GHz are available in a radiation hard version. Instead of hollow waveguides with limited bandwidth and high cost, optical fibers are used to transport the signal, allowing kilometers of fiber length with negligible attenuation. Very few passive components, essentially only an electro-optical modulator, are required near the pickup, all other active elements can be placed outside the accelerator tunnel.

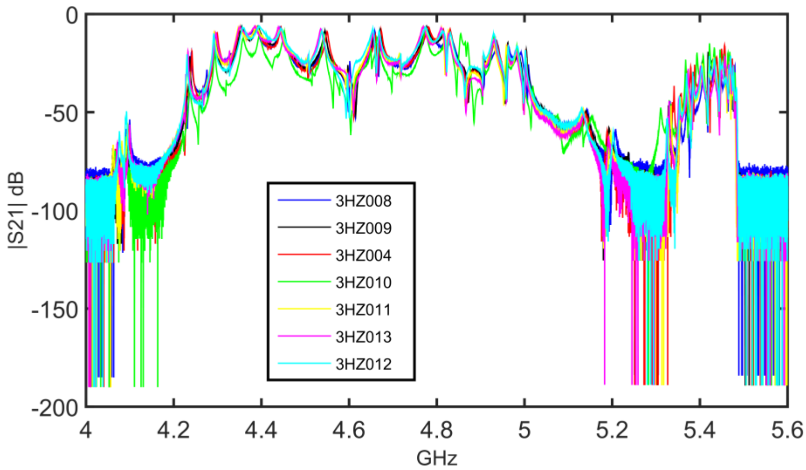


Detecting structure tilts in the spectral density of a WFM signal

The above graph, while yet far from the expected resolution, gives an idea of the power of the system. It shows the frequency spectrum of the upstream pickup versus structure to beam offset. The beam excites wakes inside the structure with the frequency correlating roughly linearly with the longitudinal position of the cell, so the spectrum contains information about the internal alignment. E.g., inside a bent structure, only the middle cells will be offset to the beam and will create a signal. In this graph, the upstream end corresponds to 15.3 GHz, the middle of the structure to 15.67 GHz. Looking at the minimum of the signal versus frequency, one sees very clearly the (intentional) tilt between structure axis and beam trajectory. With increasing resolution, we hope to see even finer details as bends or kinks.

Contrary to the structures for the SwissFEL, the E-XFEL uses superconducting 9-cell standing wave cavities for acceleration. Both the accelerating 1.3 GHz cavities and the linearizing 3.9 GHz ones are equipped with HOM couplers in order to extract power from the excited wake fields. These couplers enable monitoring the beam alignment, but also the use as a beam position monitor (HOMBPM). Some of the strongest HOMs were selected for monitoring.

While the HOMBPM principle has been initially demonstrated for the 1.3 GHz cavities, implementing the concept for 3.9 GHz cavities is quite challenging. The main reason is that the HOMs propagate along all the 8 cavities within the cryo-module. This makes extensive experimental and theoretical studies of the spectra and the mode behavior necessary. The figure shows the spectra of the cavities for the E-XFEL measured at room temperature. These spectra will dramatically change when the cavities will be connected to each other, as experience at **FLASH** had shown.



Room temperature spectra of individual 3.9GHz cavities for the E-XFEL

The electronics for the 3.9 GHz cavities down converts and digitizes the HOM signals. A new approach is used for the 1.3 GHz cavities at the E-XFEL: the HOM signals are filtered and directly sampled at a ca. 500 MS/s by a fast digitizer. This reduces the number of electronic components and therefore the phase drifts with time.

While waiting for the electronics to be ready and for the E-XFEL to be put together, beam studies are being made at FLASH at DESY. The HOM signals are already being used for beam alignment. However the HOMBPMs drift with time and cannot be used after days. A way to stabilize the signals has been found based on the frequency domain analysis. A resolution of the HOMBPMs of a few µm has been observed to be preserved over several months. Last but not least, the electronics for the E-XFEL 1.3 GHz cavities also offers the possibility to monitor the beam versus RF pulse. This should provide a tool to improve the stability of the FEL in the longitudinal space as well. This will be the first monitor of this type.

Contact

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