CORRECTOR RESPONSE BASED ALIGNMENT AT FERMI

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Abstract

The components of a free electron laser (FEL) accelerator generally need to be beam-based aligned in order to meet the design performance. We are developing a new technique, where dipole corrector responses are used instead of orbit difference measurements. When an orbit feedback is running, any change in beam orbit is compensated by the actuators, i.e. the dipole correctors. For example, the spurious dispersion is measured through orbit differences for various beam momenta in the conventional way, while dipole corrector responses are examined in the new method. The advantages are localisation of misalignments, stable measurement as the orbit is kept constant, and automatic averaging and beam jitter filtering by the feedback loop. Furthermore, the method potentially allows us to detect transverse wakefield kicks. A series of machine development shifts to test and establish the method were successfully undertaken at FERMI@Elettra.

INTRODUCTION

The components of an FEL accelerator generally need to be beam-based aligned in order to meet the design performance. For instance, the spurious dispersion needs to be corrected to avoid emittance degradation.

We are developing a new technique, where dipole *corrector responses* are used instead of the conventional orbit difference. When an orbit feedback is running, any change in beam orbit is compensated by the actuators, i.e. the dipole correctors. The advantages of the new approach are localisation of misalignments, stable measurement as the orbit is kept constant, and automatic averaging and beam jitter filtering by the feedback loop.

A particular interest in applying the method to FERMI@Elettra [1], in addition to spurious dispersion measurement and correction, is to detect transverse wakefield kicks from accelerating structures and possibly to mitigate them by optimising the beam orbit.

The results from a series of machine development shifts at FERMI are presented.

FERMI@ELETTRA

FERMI@Elettra is a fourth generation, linac based FEL a schematic layout of which is shown in Fig. 1, and its main parameters are summarized in Table 1. Electron beams are accelerated up to ~1.5 GeV and sent to a current two undulator lines, namely FEL-1 and FEL-2, to generate photon beams, which are finally transported to the experiment beamlines.

Table 1: FERMI@Elettra Operational Parameters

Parameter	**FEL-1**	**FEL-2**
Wavelength (nm)	80~20	20~4
e-beam energy (GeV)	0.9~1.5	1.2~1.5
Bunch charge (nC)	0.5	0.5
Peak current (A)	<700	400~600
Bunch length, FWHM (fs)	600	500~700
Norm. emittance, slice (μm)	0.8~1.2	1.0
Energy spread, slice (keV)	150~250	150~250
Repetition rate (Hz)	10/50	10/50

The machine is equipped with a robust orbit feedback [2,3], allowing us to apply the method without any modification.

It is noted that the average iris radius of the accelerating structures of Linac-3 and Linac-4 (see Fig. 1) is only 5 mm. The effect of transverse wakefield was studied [4,5], and it was shown that the projected emittance growth can be significant when the bunch length is long (500 μm, full width) and the misalignments are more than 100 μm in these accelerating structures. Therefore, we need to take into account, in the beam-based alignment, not only the spurious dispersion but also the transverse wakefield.

CORRECTOR RESPONSE BASED ALIGNMENT

Dispersion Source Measurement and Correction

The conventional way of dispersion measurement is to measure orbit differences due to intentionally introduced beam momentum variations. The so-called dispersion free steering (DFS) [6] algorithm is widely used for correction.

Misalignments of accelerator components generate spurious dispersion and it propagates downstream. Therefore, even when a section of the machine is perfectly aligned, the dispersion measured with the conventional way is finite because of upstream dispersion sources. Moreover, it may vary when a modification is made upstream.

On the other hand, when an orbit feedback is kept running, the corrector response is zero in a perfectly aligned section in principle, and it is constant with upstream modifications.

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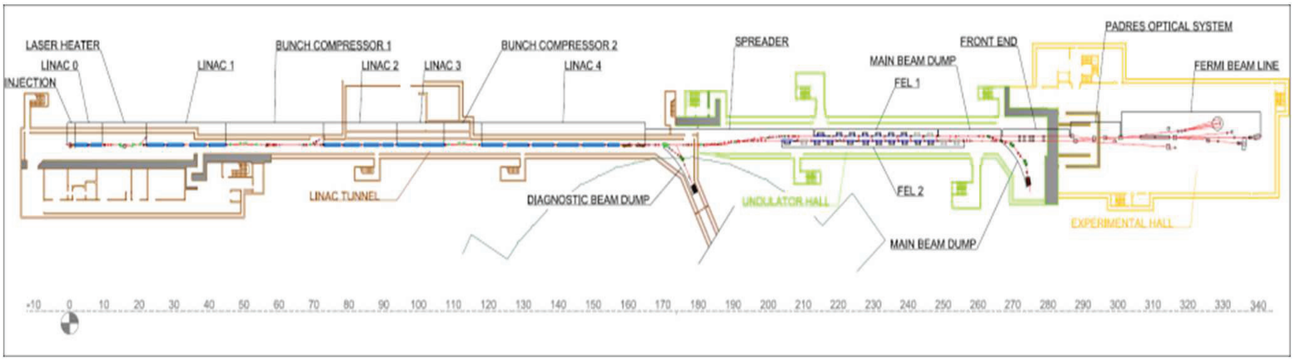

Figure 1: FERMI@Elettra schematic layout.

Hence the method localises dispersion sources while the conventional way measures and corrects the spurious dispersion in a global approach. In a correction in general, it is preferable to localise error sources and to mitigate them directly or with possible correction knobs as close to the source as possible.

We measured, at the low energy part of the machine, corrector responses to a beam momentum variation of -1.9 MeV/c introduced by varying the power of the second rf station of Linac-0 (K02). The measurement was repeated four times to evaluate the measurement stability (Fig. 2). It is seen that the statistical error is satisfactorily small.

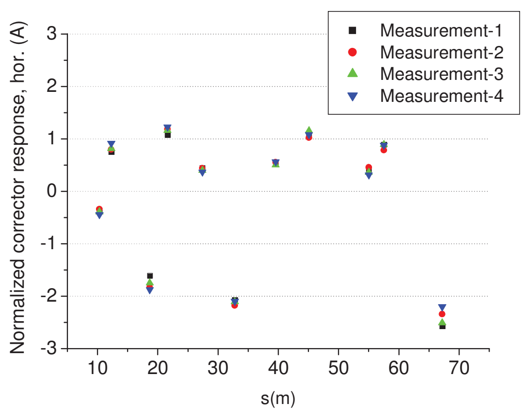

Figure 2: Successive corrector response measurements. The changes in horizontal corrector currents normalized by the relative momentum variation, *dP/P*, are plotted as a function of longitudinal location, *s*.

A sensitivity matrix necessary to compute possible corrections can be found from an optics model or from the machine. We decided to obtain it from the machine since the measurement quality was rather high. The correction knobs were the BPM references (offsets), which correspond to the targets of the orbit feedback.

The measurement was extended up to Spreader (see Fig. 1), and the offsets of the six BPMs around the end of Linac-4 (s~160 m) were used as correction knobs. As we discussed earlier, such a local correction was applicable. Figure 3 shows horizontal corrector response with and without correction.

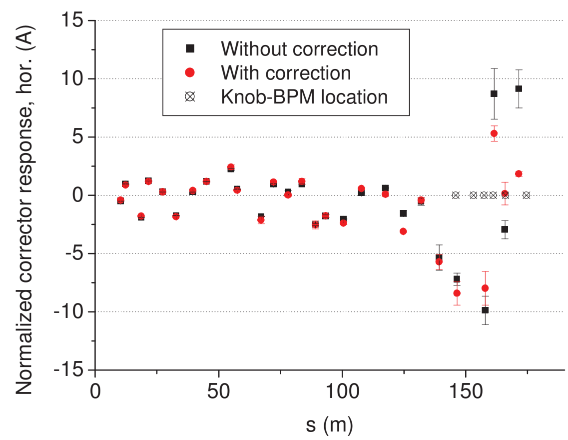

Figure 3: Corrector response with and without correction. The BPM offsets were displaced by several tens µm. The location of the BPMs used as correction knobs are also indicated. The error bars represent statistical errors from several measurements.

A momentum variation of -1.9 MeV/c was introduced again with K02. The corresponding relative momentum variation at the end of Linac-4 is only the order of 0.1 %, and the correction was, nevertheless, successful. An iteration of correction may result in a smaller corrector response.

Once the dispersion sources are mitigated as much as possible, the spurious dispersion may be finally measured and if necessary corrected with the conventional method. It should be easier to apply DFS after the dispersion source correction.

Application to Transverse Wakefield

A significant, clear difference was observed when the corrector responses were measured through momentum variations introduced differently, i.e. a variation in either rf power or phase (Fig. 4).

When the initial rf phase is close to the on-crest, the change of varies the energy of all the electrons in the bunch by approximately the same amount whereas the change of phase introduces not only an average energy variation but an energy chirp. Given that the difference

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shown in Fig. 4 is more evident through Linac-3 and Linac-4, where the iris radius is small, this difference may be attributed to the presence of transverse wakefields.

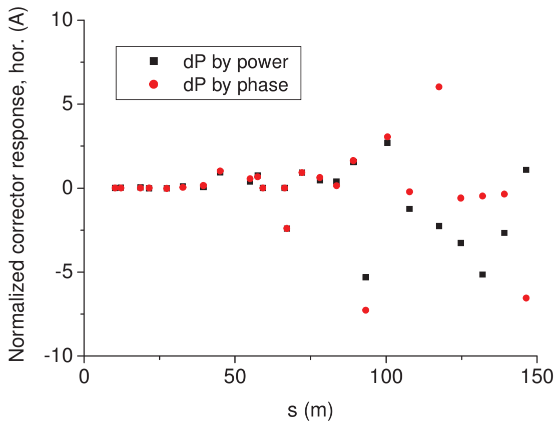

Figure 4: Corrector responses measured through a power or phase variation. The last rf station of Linac-1 (K05) was used in these measurements.

Although the corrector response with the phase variation may be a mixture of the contributions from spurious dispersion and transverse wakefield, it was possible to apply a correction and mitigate the response.

A complete distinguishing wakefield kicks from the spurious dispersion would be achieved by measuring a corrector response to a variation of the initial bunch length or charge as proposed in [7], describing a beam-based alignment technique based on the orbit difference. Finally a simultaneous correction with a proper weighting factor for the spurious dispersion and the wakefield needs to be established.

It is noted that the conventional dispersion measurement can be disturbed by transverse wakefield kicks, which depend on the beam orbit, while the corrector response based method can better separate them.

BPM and Quadrupole Relative Alignment

Some beam based alignments require relative alignment between quadrupoles and their adjacent BPMs. The conventional method to find the quadrupole centre is to vary the quadrupole field and record corresponding orbit changes.

A corrector response based alignment was successfully demonstrated at the Swiss Light Source [8], where a small statistical error of the alignment, ~2 µm, was achieved. We applied the same method to a quadrupole and BPM pair situated in the FEL2 undulator section, keeping the algorithm to align an undulator section proposed in [9] in mind.

The method is schematically shown in Fig. 5. As in the above applications, the orbit feedback is always kept running. When the excitation current of the quadrupole under alignment is varied, we may find a corrector response ($\Delta\theta_C$) to compensate for the change in feed-down dipole kick ($\Delta\theta_Q$) unless the beam is centred at the quadrupole.

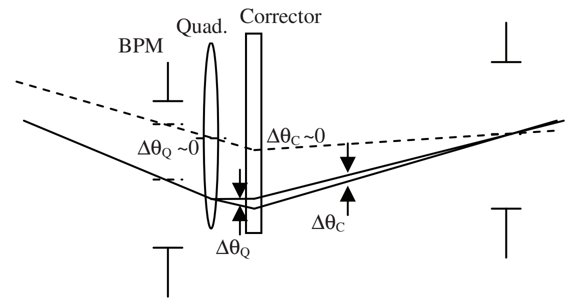

Figure 5: BPM and quadrupole relative alignment (schematic). The dashed orbit corresponds to the centre of the quadrupole, where the corrector response is zero.

As indicated in Fig. 5, there may be a residual offset between the BPM and the quadrupole because of a non-zero incoming orbit angle. However, it would be rather small when the BPM and the quadrupole are close to each other. The configuration as in Fig. 5, where BPM, quadrupole and corrector are situated in a short distance, is common in FEL accelerators, for instance, sections between accelerating structures or undulators.

The corrector response was measured as a function of the offset of the adjacent BPM (Fig. 6).

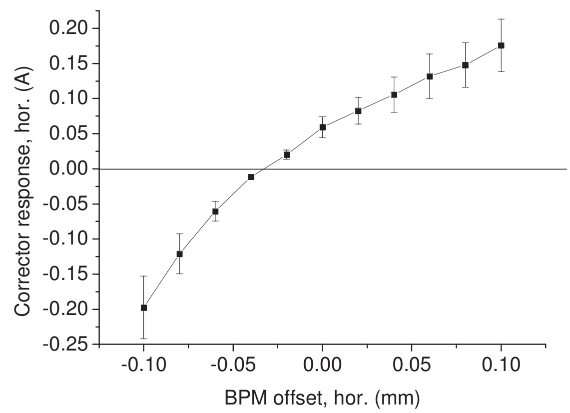

Figure 6: Corrector response as a function of BPM offset. The zero crossing corresponds to the quadrupole centre. A reasonable offset, about -30 µm, was found. It is noted that the BPM under alignment is a cavity BPM, which normally does not include an electronic offset, and thus the obtained offset corresponds to the residual misalignment after the survey alignment.

It is seen that the zero crossing, which corresponds to the quadrupole centre, is clearly found. The offset was varied in 25 µm steps in the measurement, convincing us that a relative alignment with a precision of well below 10

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μm in an undulator section, where high precision cavity BPMs are equipped, is feasible with this technique.

However, the corrector response was not fully proportional to the BPM offset, and a further study is needed for a better understanding.

CONCLUSION

The corrector response based alignment method was tested and established at FERMI@Elettra.

The method realises a localisation of dispersion sources and their local correction. The quality corrector response measurements allowed us to obtain a sensitivity matrix necessary for the correction from the machine. It should be easier to apply DFS if necessary after the dispersion source correction.

It is shown that the method has the potential to detect the transverse wakefield kicks. This capability is of interest at FERMI because of the small iris radius of Linac-3 and Linac-4 rf structures.

A precise BPM-quadrupole relative alignment through corrector response measurements was also demonstrated.

ACKNOWLEDGEMENTS

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