SIMULATIONS ON IMPACT OF THE 3.9 GHZ RF SECTION ON THE MULTI BUNCH EMITTANCE AT FLASH

Y. Kot, DESY, Hamburg, Germany.

Abstract

In order to compensate nonlinear distortions of the longitudinal phase space a RF section operated at three times the 1.3 GHz frequency of the existing TTF cavities is foreseen in the next phase of FLASH. Four modules of a nine cell 3.9 GHz cavities will be installed right after the first accelerating module ACC1. These cavities could cause additional long-range wake fields which would affect the multi bunch (MB) beam dynamics leading to increase of the MB emittance. The MB emittance at the end of the linac is determined by the strength of the transverse wake fields in the RF system. These so called higher order modes appear after any off-axis moving bunch, which could happen either due to the cavities misalignment, or by transverse position fluctuations of the injected bunches. It is intended to damp them by means of the HOM couplers, which can reduce the damping time by factor of 10^5. The misalignment of the cavities offsets is expected to be limited by 0.5 mm rms. The paper describes the results of the simulations on the dependence of the MB emittance on cavities misalignment offsets and damping strength of the HOM couplers in the planned 3.9 GHz RF section.

INTRODUCTION

In the next phase of FLASH it is planned to install four modules of a nine cell 3,9GHz cavities right after the ACC1 at 14-19meter. These cavities would cause additional long-range wake fields which could affect the multi bunch beam dynamics leading to the increase of the multi bunch emittance.

It is transverse long-range wake fields which determine the multi bunch emittance at the end of the LINAC. They appear after any off-axis moving bunch which could happen either due to the cavities offset misalignment, or by transverse position fluctuations of the injected bunches. According to the design of the cavities setup the precision of 0.5mm rms could be achieved, whereas the fluctuations of the transverse positions of the injected bunches could be kept well below this value.

In order to damp the wake fields HOM couplers will be installed which will reduce the damping time by the factor of 10^{-5}. The MB emittance blow up is also mitigated due to the RF focussing since each cavity acts as a focussing quadrupole in both vertical and horizontal planes simultaneously. This effect could play an important role if the change of the energy per cavity is not negligible compared to the bunch energy.

Thus the resulting transverse multi bunch emittance is a subject to equilibrium between the strength of the transverse wake fields due to bunch positions offsets from the cavity axis on the one side and damping strength of the wake fields due to HOM couplers on the other side.

We have simulated the MB beam dynamics for the FLASH beam line with the new 3rd harmonic RF section. The meaning of the RF focussing for the MB dynamics at FLASH has been also investigated. The results will be shown in this paper.

THEORY AND MODEL

Formulas and Theory

The technical characteristics of both 1,3GHz and 3,9GHz cavities has been described in [3] and [1,2] respectively.

The calculations of the wake fields have been fulfilled according to the following formulas:

$$W_{\parallel}^{(m)}(s) = -\sum_n \omega_n \left(\frac{R^{(m)}}{Q}\right)_n \cos\left(\omega_n \cdot s/c\right)\exp\left(-1/\tau_n \cdot s/c\right)$$

$$W_{\perp}^{(m)}(s) = c\sum_n \left(\frac{R^{(m)}}{Q}\right)_n \sin\left(\omega_n \cdot s/c\right)\exp\left(-1/\tau_n \cdot s/c\right)$$

where $W_{\parallel}^{(m)}$ and $W_{\perp}^{(m)}$ are the longitudinal and transverse wake fields accordingly, $\omega_n = 2\pi f_n$ - the frequency of the mode, $R^{(m)}$ the impedance, Q the quality factor and τ_n the lifetime of the mode. In the simulations the lowest four passbands of the monopole (m=0), dipole (m=1) and quadrupole (m=2) modes for the longitudinal and dipole (m=1) and quadrupole (m=2) modes for the transverse wake fields has been considered.

The strength of the wake fields decays in time according to the natural mode lifetime τ_{n0}. If the external damping of the higher order modes provided, the lifetime reduces according to:

$$\tau_n \rightarrow dampingfactor \cdot \tau_{n0}$$

The energy deviation and the transverse kick of the bunch j due to the wake fields of the previous bunches can be then computed as:

$$\Delta E(s_j) = -eq\sum_{i<j} W_{\parallel}^{(0)}(s_j - s_i) - eq\sum_{i<j}(x_j x_i + y_j y_i) W_{\parallel}^{(1)} + \ldots$$

$$\vec{\theta}_j = \frac{eq}{E_j}\sum_{i<j}\left(x_i \vec{e}_x + y_i \vec{e}_y\right) W_{\perp}^{(1)}(s_j - s_i) + \ldots$$

Assumptions and Parameters

We have simulated the MB dynamics during the beam transport through the LINAC at FLASH beginning at the quadrupole Q9ACC1 (13m) right after the ACC1 and ending at the entrance into the Undulator 1 at the BPM at 203m (Q22SEED). The 3.9GHz cavities have been supposed to be installed between V10ACC1 at 14m and 1UBC2 at 19m.

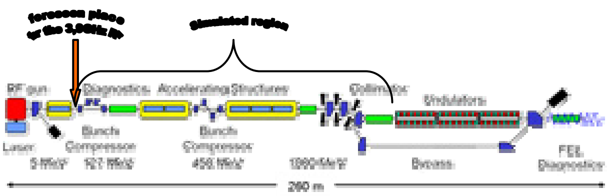

Figure 1: Schematic plan of the FLASH. Simulated region of the linac and the supposed place for the 3.9GHz RF section marked.

One particle model has been assumed for the bunch. Therefore single bunch effects were not considered. All bunches were assumed to be ideally injected on axis without multi bunch slope or position divergence. For each measurement we have taken 100 linacs with random offsets and averaged the results.

Other parameters are given in the table 1:

Table 1: Assumed Parameters in the Simulations

Bunch charge	1nC
Bunches per train	600
Bunch spacing	200ns
Pulse length	120µs
Cavities misalignment	0.5-5.0 mm rms
Cavities detuning	0.1% rms

SIMULATIONS WITHOUT RF FOCUSSING

In the simplified model the RF focussing in the cavities has been neglected. A simple drift transfer matrix has been used to perform the transfer of a bunch between two neighbour cavities. The impact of the long range wakes was described by a transverse kick and energy change in the middle of each cavity. For the transfer between modules the optics from [4] has been used.

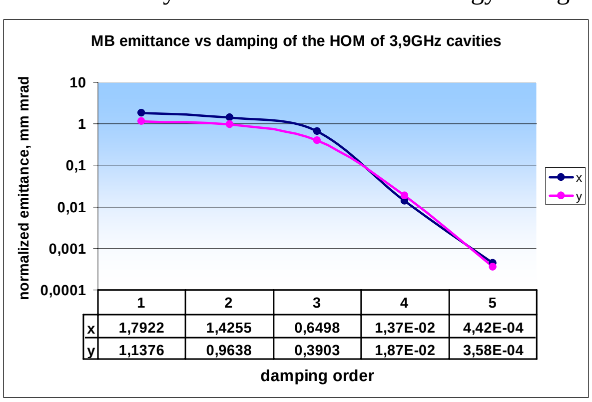

Figure 2: Multi bunch emittance in the simplified model.

The results of the simulations with the simplified model are shown in the figure 2. Here is the normalized multi bunch emittance at the end of the linac in dependence from the damping order of the higher order modes in the 3,9GHz cavities plotted. The design value of 0.5mm rms has been assumed for the cavities offset misalignment in this simulation.

An effective damping of the multi bunch blow up can be achieved if the damping order stronger than 3 (or damping factor smaller than 10^{-3}) provided. The both extreme cases without no external damping of the HOM and with the damping provided by the HOM couplers results in the normalized multi bunch emittance of 1.8mm mrad and $4.4 \cdot 10^{-4}$ mm mrad respectively. Compared to the design single bunch emittance of 1.4 mm mrad one can say that the multi bunch emittance blow up would become a serious problem if no damping of the HOM provided, whilst the damping as it is foreseen by the HOM couplers would make this phenomenon negligible.

SIMULATIONS WITH RF FOCUSSING

The simplified model which is described in the previous chapter implies the drift transfer between the centres of two neighbouring cavities. This could be a good approximation only if the energy of bunches is significantly larger than the energy gain pro cavity. However this condition isn't fulfilled for FLASH, since the energy gain pro cavity reaches about 20MeV whereas the energy of bunches is between 127MeV and 700MeV. Therefore one can expect a noticeable effect from the RF focussing which would mitigate the MB emittance blow up.

In the modified model the transfer between two neighbouring cavities in the same module has been fulfilled by means of the transfer matrixes as they follow from the optics [4]. The simulations have been done for different damping factors and cavities misalignment offsets of 0.5mm, 2.5mm and 5.0mm. For each measurement 100 linacs have been simulated and

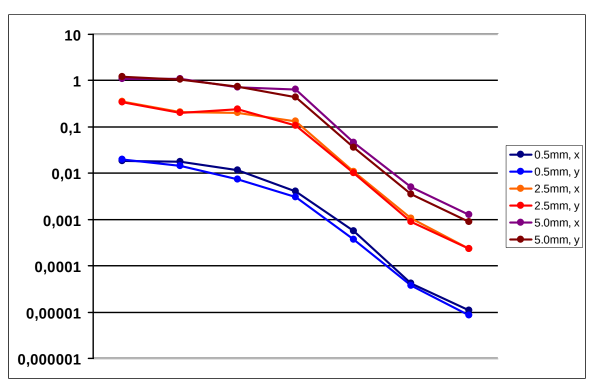

Figure 3: Normalized multi bunch emittance in the model with RF focussing as a function of damping of the higher order modes at the 3,9GHz cavities for different cavities misalignment offsets.

averaged.

Figure 3 shows the results of the simulations for the MB emittance. For the design cavities offset misalignment the MB emittance doesn't exceed 0.02 mm mrad even if the HOM remain undamped. This is reasonably smaller than the single bunch emittance. It is also about 50 times smaller than the results of the simulations in the simplified model without RF focussing.

It has been found that the MB emittance increases to the values between 10^{-3} mm mrad and 0.35mm mrad (with and without HOM couplers) if the cavities offset misalignment reaches 2.5 mm rms. For the cavities offset misalignment of 5.0 mm rms the MB emittance increases up to the range of $3.0 \cdot 10^{-3}$ - 1.2mm mrad. However even in that case the HOM couplers would damp the MB emittance blow up effectively.

The results of the simulations with and without HOM couplers for different cavities offset misalignments are summarized in the table 2.

Table 2: Multi Bunch Emittance for Extreme Cases

	With HOM couplers	Undamped
0.5 mm	10^{-5}	0.02
2.5 mm	0.001	0.35
5.0 mm	0.003	1.20

THE EVOLUTION OF THE MB EMITTANCE ALONG THE LINAC

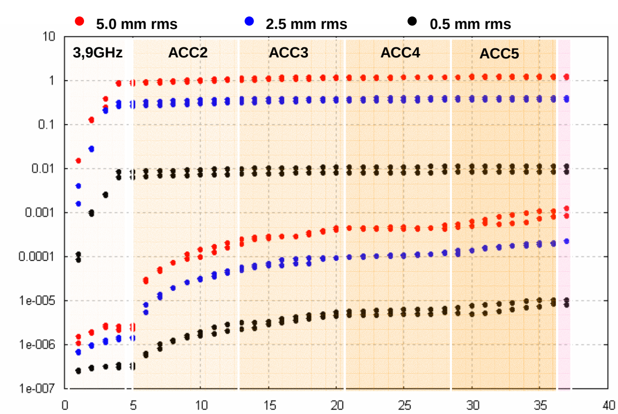

Figure 4: Multi bunch emittance along the linac. The multi bunch emittance (horizontal and vertical planes) along the linac for different cavity offset misalignments. Upper plots correspond to the case in which the higher order modes remained undamped, the lower plots – if the higher order modes are damped by HOM couplers.

The evolution of the MB emittance during the transport through the linac is shown in the figure 4 for different cavities offset misalignments.

It could be seen that the MB emittance blow up happens already in the 3,9GHz RF section if the higher order modes remain undamped. In the following sections ACC2 -> ACC5 the multi bunch emittance remains almost unchanged for all cavities misalignment offsets.

In the presence of the HOM couplers the multi bunch emittance is slightly increasing also during the passage through the 1,3GHz cavities. Nevertheless it remains negligible all the time.

CONLCLUSIONS AND DISCUSSION

The multi bunch emittance at FLASH depends crucially on the damping factor of the HOM modes at 3.9GHz cavities. The damping factor of 10^{-5} as it is foreseen by the HOM couplers provides suitable bunch train quality with negligible multi bunch emittance for the cavity misalignment offset up to 5.0mm rms. If the 3.9GHz cavities are operated without damping of the HOM, the multi bunch emittance still remains reasonably smaller than the single bunch emittance. However the bunch train may become unusable since a lot of bunches arrive too far away from the average position of bunches in the phase space.

The RF focussing plays an important role by damping the multi bunch emittance expansion. The simulations in which the RF focussing has been taken into account indicate the multi bunch emittance 50 times smaller than in the case where the RF focussing has not been considered.

If the HOM are not damped or only weak damped, than the emittance blow up occurs at the very beginning of the linac, mostly during the passage through the 3,9GHz cavities.

REFERENCES

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[4] V. Balandin, N. Golubeva "Matlab Functions for Calculations of the Linear beam Optics of FLASH Linac"