STATUS OF THE 3RD HARMONIC SYSTEMS FOR FLASH AND XFEL IN SUMMER 2008

E. Vogel[3], A. Bosotti[2], W. Decking[3], M. Dohlus[3], H. Edwards[1], E. Harms[1], M. Hoffmann[3], M. Huening[3], J. Iversen[3], K. Jensch[3], T. Khabiboulline[1], G. Kreps[3], T. Limberg[3], A. Matheisen[3], W.-D. Moeller[3], P. Pierini[2], K. Rehlich[3], A. Schmidt[3], J. Sekutowicz[3], D. Sertore[2] and W. Singer[3] for all third harmonic collaborators
[1]Fermi National Accelerator Laboratory (Fermilab), Batavia, Illinois, 60510 USA
[2]Istituto Nazionale di Fisica Nucleare (INFN), LASA, 20090 Segrate (Milano), Italy
[3]Deutsches Elektronen Synchrotron (DESY), Notkestraße 85, 22607 Hamburg, Germany

Abstract

Ultra short bunches with high peak current are required for the creation of high brilliance coherent light in the VUV and x-ray range in undulators. At the Free Electron Laser in Hamburg (FLASH) and the European x-ray free electron laser (XFEL) they are obtained by a two stage bunch compression scheme based on acceleration off the rf field crest and transverse magnetic chicanes. The deviation of the rf field's sine shape from a straight line leads to long bunch tails and reduces the peak current. This effect can be eliminated by adding a third harmonic rf system [1, 2, 3]. This paper gives an overview on the actual status of the beam dynamical examinations, as well as on the development of the third harmonic sub-systems like modules, cavities and radio frequency systems for FLASH and the XFEL. For an basic overview on the activities we refer to [3].

INTRODUCTION

At the linear accelerator based free electron lasers FLASH and XFEL bunches are generated by a normal conducting photocathode rf gun and then accelerated by a superconducting linear accelerator. While passing through undulators the bunches emit high brilliance coherent light. The emission process requires high electron peak currents and small transverse emittances. Collective effects restrict the minimum full width bunch length obtained from the photocathode rf gun. The high peak currents are obtained by compressing the bunch length in the first part of the superconducting accelerator (Fig. 1).

Accelerating the bunches off the rf field crest results in an energy chirp from the bunch head to the tail. In the bunch compressors the trajectory of the bunch head becomes longer than the trajectory of the bunch tail resulting in a compressed bunch due to the different transit time. Both the sinusoidal accelerating wave and non-linear collective effects lead to asymmetric bunches with reduced peak current and long tails. By adding a higher harmonic rf system, the voltage seen by the bunches and the collective effects may be linearised. The bunch compression becomes much more effective.

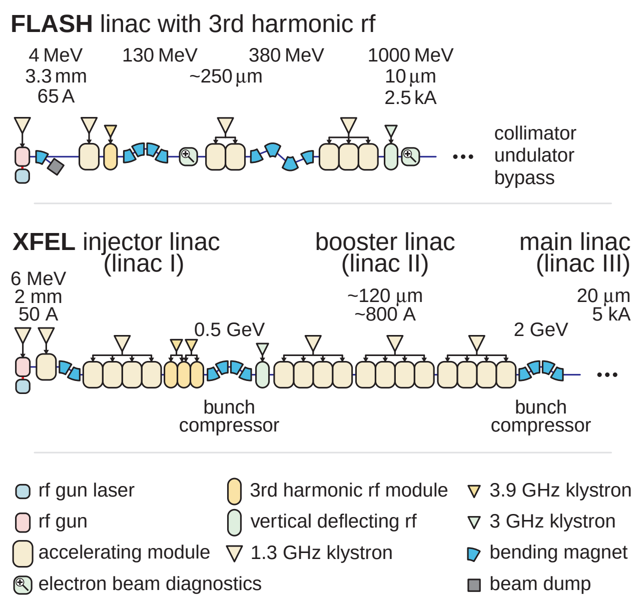

Figure 1: Sketch of the FLASH accelerator and the first part of the European XFEL accelerator.

BEAM DYNAMICS

Beam passing a third harmonic section suffers from coupler kicks, short range (intra bunch) and long range (bunch to bunch) effects. For the XFEL we decided to use a coupler arrangement where every second cavity is rotated around the cavity longitudinal axis [3, fig. 4] resulting in a transverse beam blow up in the order of 2%. The FLASH configuration or all couplers at the same side would result in a blow up by 40% and 100%, respectively. The r.m.s. of the difference between the cavity cell centre and the beam trajectory has to be below 0.3 mm for keeping the transverse blow up due to transverse wake fields below 5%. Long range effects caused by the lower frequency higher order modes (HOMs) are damped by the cavity HOM absorbers. Higher frequency HOMs can be trapped in a string of cavities with different spectra for the frequencies above 10 GHz. The effects on the beam are expected to be cured by an arrival time feedback system [4] and we can go without beam pipe HOM absorbers inside modules. Absorbers between modules should be sufficient.

At FLASH, beam steering in the 3.9 GHz (ACC39) section for reducing 3.9 GHz coupler kick and wake field effects can be done using a steering magnet after the gun and at the end of the first 1.3 GHz (ACC1) module. We have started to study the effect of ACC1 on the beam while generating orbit bumps at the later ACC39 position for comparison with the future situation when ACC39 is installed.

FLASH 3RD HARMONIC MODULE

The principal development work for the third harmonic rf is performed at Fermilab by developing and building the module ACC39 for FLASH [5]. It consists of four 3.9 GHz cavities of which one has been horizontally tested. The gradient of 22 MV/m is well above the desired operational gradient of 14 MV/m. Additional cavities will soon be tested horizontally [6].

A number of tests have been performed to study the potential consequences of the module transportation from Fermilab to DESY. Therefore the module and cold mass has been equipped with four mock-up cavities showing the weight of the original cavities. After transportation of this module by truck from Fermilab to the Chicago airport O'Hare and back the cavity alignment was unchanged within the required limits.

Before installation into the FLASH accelerators, we plan to test the module at the cryo-module test bed (CMTB) at DESY. It will be the first cold test of the assembled module. The preparation required for this test has been started.

HIGH POWER RF

At Fermilab the first built 3.9 GHz klystron is operated for coupler processing and for the horizontal cavity tests. The second built klystron is foreseen to operate ACC39 at the CMTB and in FLASH at DESY. Operation tests for this klystron take place these days.

We started the call for tender process to purchase a modulator for the third 3.9 GHz rf station. It is required for processing the couplers for the XFEL 3.9 GHz prototype cavities. Beside for coupler processing it serves for XFEL module tests at the CMTB followed by the 3rd harmonic operation at the XFEL.

The results of the klystron test at DESY and the operational experience from the Fermilab klystron may be used to propose improvements for future 3.9 GHz klystrons. Therefore, purchasing the klystron for the third rf station will first start after the DESY klystron tests.

RF CONTROL

The rf field is controlled by an EseCon controller at the horizontal 3.9 GHz cavity tests at Fermilab. At FLASH the SimCon controller [7] is used to control the 1.3 GHz rf field in the injector part (rf gun and ACC1). It is also foreseen for the later modules. For keeping the future maintenance effort low, SimCon has also been chosen for 3.9 GHz rf control at the CMTB and FLASH. This requires the development of down converters as interface between the 3.9 GHz rf and the ADCs of the controller.

A collection of the requirements on the individual parts and the control loops [3, fig. 7] is in progress. Discussions on the control system interfaces has just started. Nevertheless, a first initial laboratory setup of an SimCon controller adapted to 3.9 GHz exists.

XFEL CAVITY PROTOTYPES

About one year ago, we ordered three 3.9 GHz cavities [8] built and surface treated by industry with the goal to industrialize the cavity production. Within this process we exchange and examine ideas for design changes with the vendor to simplify the production and to ease the survey. Some of the changes are desirable due to the different the electron beam welding apparatus available to Fermilab and by the vendor. As a result we look into topics like the magnetic shielding and the effectiveness of the tuner. To verify the changes are uncritical we prepare everything to perform horizontal tests with this XFEL type 3.9 GHz cavities. We revise and procure parts like the He-vessels, tuner, magnetic shielding, power-coupler and so on.

XFEL CRYOMODULE

The cryo-modules for the XFEL differ from the older cryo-module designs used in the FLASH injector area. In the FLASH injector, the two phase helium line is between the cavities and the He return pipe. Due to the smaller diameter of the new outer vessel, the two phase line is shifted sideways in the newer designs also foreseen for the XFEL. This results in two types of dressed 3.9 GHz cavities because of the alternating coupler positions.

Our baseline inner third harmonic module design consists of a string of eight cavities, a quadrupole magnet, a beam position monitor and valves at the beginning and the end. Between those modules beam pipe HOM absorbers are foreseen. The module together with the beam pipe absorber covers a length of 5.8 m. Three of these modules, with a total of 24 cavities, will be used to build up the third harmonic voltage of 108 MV [3]. Two rf stations, each driving 12 cavities ($1\frac{1}{2}$ modules) are foreseen.

We skipped the option enabling a cavity alignment in the cold as mentioned in [3]. An r.m.s. of 0.3 mm for the cavity to cavity alignment seems to be feasible without such a complicating feature.

SUMMARY AND OUTLOOK

Due to the smaller diameter and higher frequency of the third harmonic rf, the influence on the beam is substantially higher than at the 1.3 GHz accelerating sections. After calculating these effects we have a clear picture on the required arrangement of the cavities and coupler positions in the module. Some questions like the heat load induced by trapped HOMs are still under investigation.

At the construction and assembly of the FLASH third harmonic module at Fermilab two cavities are nearly ready for string installation and four other cavities are in the queue for being tested horizontally soon. Module transportation tests show quite promising results so that we can hope ACC39 arrives at DESY without any damage for being cold tested, installed an operated.

FLASH operation requires the 3.9 GHz rf station present at DESY. To enable parallel coupler processing, horizontal and CMTB tests, we already started to purchase an additional 3.9 GHz rf station. The development of the 3.9 GHz rf control based on the SimCon technology is on going.

Three 3.9 GHz cavities are on the way to being built and surface treated by industry. Within this context some design changes appear desirable to simplify the production by the vendor. The resulting XFEL 3.9 GHz cavities will be horizontally tested to verify the changes are uncritical.

The over all design of the XFEL third harmonic cryomodule has not been started. Nevertheless, our baseline is eight cavities with alternating coupler positions per module plus a package of a quadrupole magnet and a beam position monitor.

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