

BEAM DIAGNOSTICS REQUIREMENTS FOR THE NEXT GENERATION LIGHT SOURCE*

S. De Santis[#], J. Byrd, J. Corlett, P. J. Emma, D. Filippetto, M. Placidi, H. Qian,
F. Sannibale LBNL, Berkeley, CA 94720, USA

Abstract

The Next Generation Light Source (NGLS) project, in its standard configuration, consists of a 2.4 GeV superconducting linac accelerating sub-1 μm normalized emittance bunches used to produce high intensity soft X-ray short pulses from multiple FEL beamlines. The 1 MHz bunch repetition rate, and the consequent high beam power, present special challenges, but also opportunities, in the design of the various electron beam diagnostic devices. The wide range of beam characteristics, from the photoinjector to the undulators, require the adoption of different diagnostics optimized to each machine section and to the specific application of each individual measurement. In this paper we present our plans for the NGLS beam diagnostics, discussing the special requirements and challenges.

INTRODUCTION

The design concepts for the NGLS, a proposed fourth generation light source, have been described in [1-2]. Low-emittance bunches are generated at a high repetition rate, accelerated in a superconducting linac while being shortened by bunch compressors, and fed to various FEL beamlines by an RF-based spreader for the production of ultra-short soft X-ray pulses. The delivery of bunches with appropriate characteristics for the generation of such pulses relies on the accurate measurements of a number of beam parameters (Tab. 1) throughout the machine.

Table 1: Electron Beam Parameters

Final Beam Energy (GeV)	E_f	2.4
Bunch Charge (pC)	Q_b	300
Bunch Length (fs)	σ_t	2900-170
Bunch Transverse Size (μm)	σ_x, σ_y	100's-40
Normalized Emittance (μm)	ϵ_N	1
Relative Energy Spread (%)	σ_E	1-0.05
Beam Power (kW)	P_{beam}	720
RF Frequency (GHz)	f_{RF}	1.3
Bunch Repetition Rate (MHz)	f_{rep}	1

*Work supported by the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.
#sdesantis@lbl.gov

The high bunch repetition rate and consequent elevated beam power are a distinctive feature of the NGLS which present special challenges from the point of view of the beam diagnostics, not usually encountered in linear accelerators, but on the other hand offer unique opportunities as it will be described in the following sections.

The type of beam measurements that need to be performed can be subdivided in three main categories:

- Bunch-by-bunch measurements.
- Sampled beam measurements.
- Measurements for machine commissioning/set-up.

These categories will be described in the following sections, with the individual measurements belonging to each one and the devices we plan to use.

BUNCH-BY-BUNCH MEASUREMENTS

Measurements belonging to this category need to be performed on every single bunch and have to be minimally invasive therefore. These are the measurements used for the trajectory control, feedback systems, timing measurements provided to users. Additionally, bunch-by-bunch charge measurements can be used as part of the machine protection system, although in this case the single bunch resolution level is not necessary, but it is sufficient to perform such measurement averaged over an adequately short time window, which for a 1 MHz bunch repetition rate can be of the order of

Beam Trajectory

The transverse position of each bunch is measured all along the linac. The target requirement for the trajectory control is to maintain an RMS transverse stability below 5% of the beam transverse dimensions. This means that the position monitors have to measure the bunch position with a resolution of 10 μm or better. We plan to use stripline BPM's derived from the ones we have designed for the Advanced Photoinjector Experiment currently in use [3]. With a 300 pC bunch charge in our standard 1.5" ID circular beam pipe the readout electronics currently developed can easily achieve the required resolution in a single-bunch measurement. The shorted stripline design allows to install the BPM's in a compact fashion together with the quadrupoles.

Although a simpler button BPM could achieve the same resolution at full charge, we have chosen striplines with their larger coupling impedance in order to be able to satisfy the resolution requirement even with a reduced

bunch charge, during commissioning or an operation mode at higher repetition frequency currently under study.

Higher accuracy in the measurement of the transverse position is required in narrow vertical gap chambers of the FEL undulators, where the beam transverse dimensions are also at their smallest value of around 40 μm. Although at full charge it would still be possible to obtain the desired 2 μm resolution by integrating the measurement over a time span consistent with the response time of the orbit feedback, we intend to use more accurate cavity BPM's, which can achieve the spec on a single-bunch basis, even at reduced charge.

The 3.3 GHz cavity BPM's proposed for the XFEL [4] look like a promising solution being compatible with our beampipe size and can be fitted in the interundulator spaces provided for housing quadrupoles. A potential issue with a high repetition beam is the excitation of oscillations in the cavity modes, which survive until the passage of the following bunch. Fundamental (monopole) mode and the first dipole mode are the most critical, since they have both the highest Q values and the first can perturb the beam with its high shunt impedance, while the residual oscillation in the second can affect the measurement precision. The decay time for these modes $\tau = 2Q/\omega$ is around few 10's of nanoseconds, which means that they can be safely used with bunch repetition frequencies as high as 1 MHz, which is the maximum value we plan for.

Measurements for Beam-based Feedback

To improve the stability of the X-Ray pulses we plan to use a bunch-by-bunch feedback system to control the stability of the energy, peak current and timing jitter of the electron beam [5]. To this end the relative changes in energy, energy spread and bunch length of every bunch are measured in several points along the linac and the data is used for the control of the accelerating modules parameters.

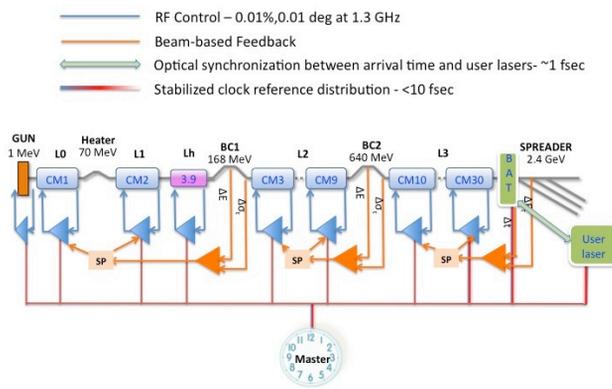


Fig. 1: NGLS Beam-based Feedback System Diagram.

Figure 1 shows the feedback system diagram. In particular the orange lines represent the flow of the bunch energy and length relative changes measured in the

dispersive regions (Laser Heater, Bunch Compressors 1 and 2, Beam Spreader).

Relative energy change $\Delta E/E$ would be measured in the Bunch Compressor with the target resolution of 10^{-5} , by measuring the horizontal position changes of the bunch centroids with a 5 μm resolution. Due to smaller dispersion such a measurement would yield only a 10^{-4} resolution in the Laser Heater. We are evaluating whether the feedback can still work with the reduced resolution, or we need to develop a more accurate BPM for the laser heater. Wide aperture (40 mm) cavity BPMs developed at DESY [4] could perhaps be a viable solution.

Measurements of the bunch length at the 150 fs level have been demonstrated at JLAB using spectral analysis of coherent synchrotron radiation [6]. We intend to implement analogous measurements using the emission from the exit dipoles of the chicanes in the two bunch compressors.

Beam Dump Diagnostics

Differently to the previous two categories, these measurements are destructive, but they can still be performed on every bunch since they take place in the beam dumps, when bunches are discarded.

The objective of this diagnostics is to provide an accurate analysis of the bunch charge, energy, energy spread and profile which would be possible by using very invasive methods and using the large 1.5 m vertical dispersion introduced by the magnets steering the beam into the high power dumps. These measurements would be used to tune the FEL's and monitor their operations.

SAMPLED BEAM MEASUREMENTS

The uniquely high bunch repetition rate of the NGLS offers the opportunity of performing more invasive measurements on a small subset of the bunches which can provide more accurate information on the beam properties (projected and sliced) and can still do so at a high enough rate.

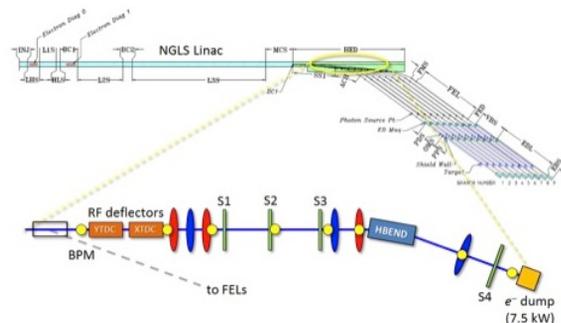


Fig. 2: Layout of the High Energy Diagnostic line. RF deflectors ("YTDC" and "XTDC"), spectrometer bend ("HBEND") and four beam screens ("S1" through "S4") are shown, together with quadrupole magnets, BPM's, beam dump and pulsed input dipole magnet.

Such measurements will be performed in three off-axis diagnostic lines, one after the Laser Heater, one after the Bunch Compressor 1 and one at the end of the linac, each of which can steal bunches from the main linac at a 100 - 1000 Hz rate, therefore leaving essentially the entire beam still available for the generation of X-Ray pulses.

The off-axis diagnostic lines can also be used on the entire beam during commissioning and machine setups, although bunch charge and repetition rate have to be selected within the maximum power handling capabilities, which is set by the dumps.

Figure 2 shows the line at the end of the linac (High Energy Diagnostic line). Two RF deflectors can streak the beam vertically and horizontally and be used in conjunction with a horizontal dipole spectrometer.

Measurements provided are:

- Multiscreen projected emittance and beam size.
- Single-screen emittance (quad-scans).
- Time-resolved (slice) emittance.
- Time-resolved energy and energy spread.
- Bunch length and longitudinal bunch profile.
- Bunch-by-bunch energy jitter.

As the other two diagnostic lines are concerned, besides the obvious changes due to the considerably lower beam energy, the only substantial difference is the presence of only one RF deflector, operating along an axis perpendicular to the plane of the spectrometer.

Resolutions achievable by such systems are listed in Tab.2 and satisfy the NGLS needs.

Table 2: Off-Axis Diagnostics Lines Measurements Resolutions.

Norm. Emittance (proj/slice)	<100 nm
Transverse Size	$<\sigma_{x,y}/20$
Bunch Length	10 μm
Energy Jitter	10^{-5}
Energy Spread	100 keV
Bunch Time of Arrival	10 fs
Bunch Charge	3 pC

MEASUREMENTS FOR MACHINE SETUP AND COMMISSIONING

The last category includes beam measurements that are fully invasive and are generally not performed during user operations. All the measurements previously seen can also be performed under special beam conditions, during commissioning, or machine setups, but there are a few diagnostic devices, which are only used in such circumstances.

In particular, we plan to have dedicated low-energy diagnostics for the injector including bunch charge,

energy and energy spread, which would be used to tune the photoinjector. Also a dark current monitor, based on a resonating cavity is in our plans [7]. Measurements of the transverse emittance with multiple beam profile monitors, or by quad-scan technique are also planned at a minimum at the end of the linac, in order to be able to measure the emittance delivered to the FEL beamlines before the High Energy Diagnostic lines is installed.

CONCLUSIONS

We have described our conceptual design of the electron beam diagnostics for the NGLS. Its unique characteristics in terms of high bunch repetition rate present some special challenges in terms of beam power that needs to be handled, but also offer the opportunity of using new approaches to beam quality monitoring and for using measured beam properties to feedback on the RF controls and provide unprecedented levels of stability, which is vital for a light source such as the NGLS.

REFERENCES

- [1] J. Corlett, et al., "Next Generation Light Source R&D and design studies at LBNL", in Proc. of IPAC 2012, New Orleans, Louisiana, USA, May 20-25, 2012, TUPP070.
- [2] J. Corlett, et al. "Design Concepts For A Next Generation Light Source At LBNL", TUOCNO05, these proceedings.
- [3] S. De Santis, et al, "Design of the Stripline BPM For The Advanced Photoinjector Experiment," in Proc. of IBIC 2013, Oxford, United Kingdom, September 16-19, 2013.
- [4] D. Lipka, " High Resolution Cavity BPMs in the Context of the European XFEL", 8th DITANET Topical Workshop on Beam Position Monitors, CERN, Geneva, Switzerland, January 16-18, 2012.
- [5] J.M. Byrd, et al., "Towards High Energy and Timing Stability in SCRF Linacs" TUANO01, these proceedings.
- [6] P. Evtushenko, et al., "Bunch Length Measurements at JLAB FEL", in Proc. of FEL 2006, BESSY, Berlin, Germany, Aug 27 - Sept. 1, 2006. THPPH064.
- [7] D. Lipka, et al., "Dark Current Monitor For The European XFEL", in Proc. of DIPAC 2011, BESSY, Hamburg, Germany, May 16-18, 2011. WEOC03.