CLOSING PLENARY SUMMARY OF WORKING GROUP 4 INSTRUMENTATION AND CONTROLS FOR ERL2011*

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Abstract

Summary of the working group 4 activities, presented in the closing plenary session.

OVERVIEW

Working group 4 was charged with presentations and discussions on instrumentation and controls with regards to Energy Recovery Linacs (ERL). There were 4 sessions spanning 3.5 hours in which 7 talks were delivered, the first being an invited plenary presentation. The time allotted for each talk was limited to 20-25 minutes in order to allow 5-10 minutes for discussion. Most of the talks were held in joint session with working group 5 (Unwanted Beam Loss). This format was effective for the purpose of this workshop. A final series of discussion sessions were also held with working group 5.

PRESENTATIONS

The working group 4 presentations can be separated into 3 groups, the first being a plenary talk about the instrumentation and controls at the existing ERL at Cornell. The second group described instrumentation technology that is presently in use at other similar machines that can be applied to ERLs. The third group explained the details of two new ERLs that are under construction, and their respective instrumentation systems.

B. Dunham (Cornell): Operations, Controls and Diagnostics for High Power Electron Injectors

In this plenary talk Bruce described many aspects of the instrumentation and controls at the ERL Injector Prototype at Cornell (13MeV, 77pC/bunch, 1.3GHz bunch rate). He described the challenges ahead to provide diagnostic systems with increased resolution and wide dynamic range (10^6-10^9) that will be needed to assure beam stability and synchronization. With regards to controls systems, he described the features and advantages of EPICS and looks forward to a new version that will be released soon. He also described the DOOCS (Distributed Object Oriented Controls System) that was developed at DESY. Using this it is easy to write applications in C++, it has advantages for high data-rate DAQ streams, and it communicates well with EPICS servers.

Bruce explained techiques used at the Cornell ERL Injector to measure transverse emittance, and a new way to use two stationary slits each with a respective upstream corrector dipole pair and a downstream Faraday Cup. Slice emittance measurements were made using the stationary slits, a deflection cavity, and downstream view screen as shown in Figure 1. He also described details about the deflection cavities used at Cornell and KEK, the application of these to map the time axis onto transverse coordinates, and how to make longitudinal phase space measurements. More descriptions were presented about bunch arrival time monitors, and electro-optic profile diagnostics using a laser.

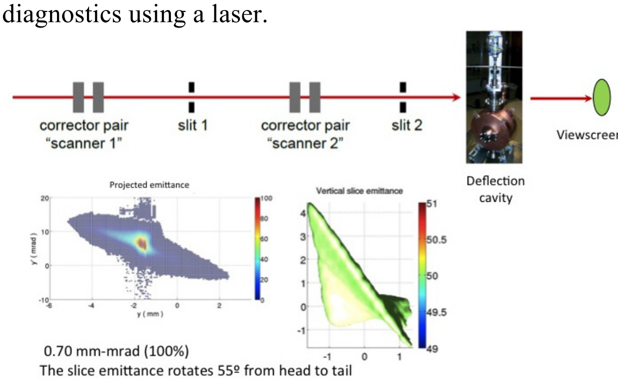

Figure 1: Slice emittance using correctors, slits, deflection cavity, and view screen.

The next topic focused on issues with regards to high current operations. The importance of the gun laser intensity and position stabilization was explained. Cornell is developing laser fast-feedback systems as a remedy; progress to date was described, as well as future plans for laser position stabilization to 10 microns.

This was followed by information about beam halo generation, causes, and methods to measure halo. Images were shown of halo measurements using the solid screens, coronagraph, screen with hole, and adaptive mapping. He emphasized the importance of minimizing the surface roughness to < 2nm rms of the mirror used to transport the laser to the photocathode.

The final topic was about valuable lessons learned, operational experiences, raster scanning, temperature monitoring, and beam diagnostics at the Cornell beam dump.

In conclusion he commented that there have been a lot of great developments for ERL diagnostics in the past 2 years, but there is still a long list of things they need and want. Some items that were requested to improve the ERL instrumentation systems include: easy to use fast DAQ and transient capture, large dynamic range CCD cameras that are inexpensive, non-intercepting emittance measurements, really fast laser monitoring to look between pulses, smarter sub-systems with more status and fault indicators, simpler non-intercepting bunch length monitors, and a more affordable streak camera.

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M. Tobiyama (KEK): Turn-by-Turn Monitor Using a Fast Gate Switch

This presentation describes the motivation and progress to employ an electronic fast gate switch to enhance the existing beam position monitoring system at the SuperKEKB facility in order to improve the control of the betatron tune during collisions. Makoto explained how his team's developments might be useful at ERLs to measure beam positions near the Linac where both low and high-energy beams are present and interleaved in time.

A variety of candidate switches were described, the Hittite HMC234C8 was chosen for integration and testing with beam. This switch is a broadband high isolation non-reflective GaAs MESFET SPDT switch in a non-hermetic surface mount ceramic package, DC–8GHz, with a 3ns switching time. The technique that was used to provide improved isolation and switching noise cancellation using several Mini Circuits MCL SBTCJ-1W power splitters/combiners was described in detail. System performance was described with scope and network analyser waveforms, an example is shown in Figure 2.

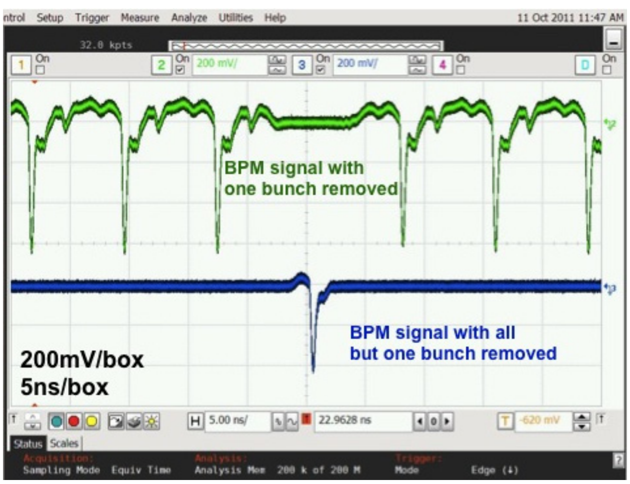

Figure 2: Fast gate switch used to gate BPM signal. The switch has two output ports, both traces are shown.

There were suggestions presented that could improve this fast switch system for ERL applications. These include the need for better time domain response from the BPM pick-ups. Stripline BPMs were used at the Super KEKB; button electrodes will likely provide better time response. Also a switch with faster response can help, but this can be complicated by difficulties driving the switch over long cables in a noisy accelerator environment. Finally, improvements to symmetry of the printed circuit board in the noise cancellation circuit can improve performance.

H. Maesaka (RIKEN/SPring-8): Beam Diagnostic Instruments for SACLA

This presentation by Hirokazu described a wide variety of impressive beam diagnostic instruments used along the series of linear accelerators at this 600m long, 8GeV facility that has 3kA peak, 30fs electron bunches.

Beam position measurements are made using the RF Cavity BPM in the TM110 dipole mode, and the TM010 is used to determine the phase reference and the bunch charge. The resonant frequency of this BPM is 4.760GHz. The position resolution is < 0.6 microns rms at 7GeV, 0.1nC. The beam arrival time resolution is ~27fs.

Beam profiles are measured using YAG:Ce screens and CCD cameras. Initially the images also included undesired coherent OTR light. This was later masked using a 5mm wide shield upstream of the camera lens. There are future plans to use a fast gate CCD camera (C10042) to view only the slow (~70ns decay time) scintillation from the YAG:Ce, and ignore the prompt C-OTR radiation.

A custom designed fast differential current transformer was described that achieves a 200ps rise-time. It provides reasonable linearity, for bunch lengths > 400ps FWHM.

Details about a transverse deflection cavity that operates at 5.712GHz and 60MV were presented. Results are shown in Figure 3.

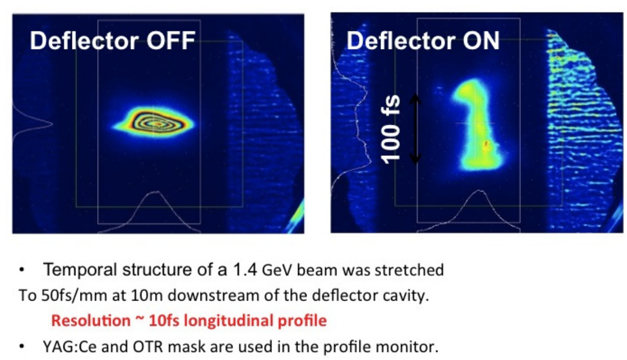

Figure 3: Electron bunch data from the SACLA deflector cavity.

More details were presented about streak camera implementation, as well as the system configuration and data from a coherent synchrotron radiation monitor that employs a pyro-electric or THz diode. An electron bunch timing pick-up using an electro-optic crystal is under development. This system uses an 110fs Ti:Sapphire laser pulse, and complex optics to transport to the laser through a viewing port to a ZnTe electro-optic crystal located in the beam line vacuum chamber. They expect to achieve ~100fs timing resolution.

Many of the experiences and advances in electron beam diagnostics systems described by Hirokazu can be useful at energy recovery linacs.

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H. Maesaka: Design and Performance of the Synchronization System for SACLA

Hirokazu's second talk described the effort to improve the synchronization system at SACLA with the purpose of providing stable x-ray lasing. System details about the optical RF signal distribution method were presented. The 2856MHz master oscillator is phase locked to 10MHz and 100MHz oven controlled crystal oscillators. Frequency dividers generate sub-harmonic signals. The distribution system employs E/O and O/E converters using an LN modulator (Mach-Zehnder interferometer), and fast photodiode, respectively. Water-cooled electronics racks were installed, as well as temperature regulated long length fiber optic cable ducts, all with stability of 0.2K (pk-pk). A low-noise linear regulated 24V DC power supply with an FFT spectrum noise floor ~ -140dBV/root Hz was used for subsystem power.

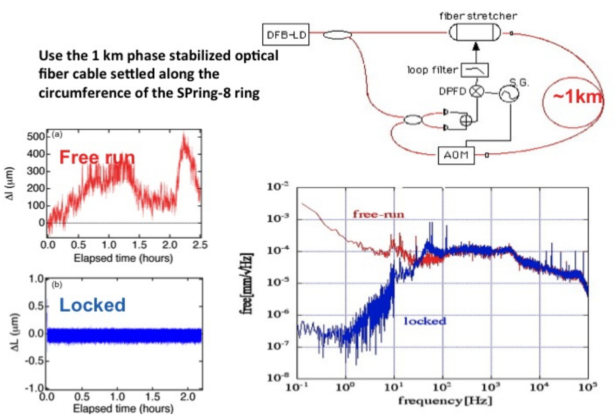

Figure 4: Experiment of fiber length control.

A fiber length control system was developed as shown in Figure 4. The system was tested using the existing 2km phase-stabilized optical fiber along the circumference of the SPring-8 ring accelerator. The displacement signal outputted from the feedback circuit is proportional to the fiber optical length change. The optical length control for the fiber worked well, and decreased the displacement to less than several micron-meters of its optical length in a frequency range of less than 50 Hz.

A custom designed low-level RF control system was described. Since each facility has many unique requirements, this may not be directly beneficial for use at an ERL, but some of the subsystem techniques can be helpful.

T. Naito (KEK): Development of Femtosecond Timing Distribution System

Precise timing reference clock distribution is required for the new compact ERL at KEK, and also at future accelerators such as Super KEK, and the ILC. Takashi described the previous progress at KEK, and the present similar systems at DESY and at LCLS at SLAC. A diagram of the system presently under development at KEK is shown in Figure 5. Experimental test hardware configurations were described and measurement data was presented. This included plots of long-term stability, length stability, and feedback phase versus fiber length.

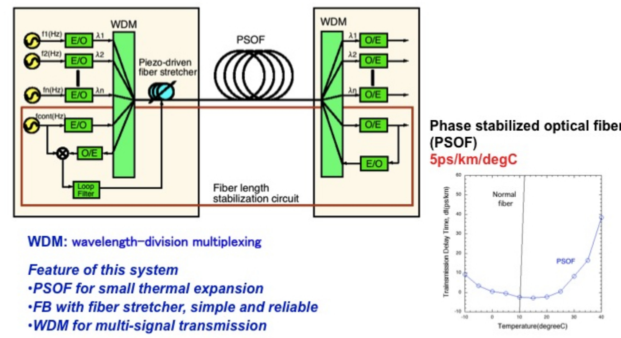

Figure 5: Femtosecond timing distribution system layout.

A precise reference clock distribution system using optical links and a feedback circuit was developed and was able to achieve stability of ~50fs for 900m of optical fiber, using 2856MHz clock transmission.

Efforts are underway to improve performance of several aspects of the system. In order to achieve <20fs stability, they will improve temperature stabilization of the TX/RX control box to 0.01deg C, as well as the possible use of a higher frequency 11.4GHz clock. To confirm long distance stability, a 10km long phase stabilized optical fiber will be tested. To confirm long term stability a system will be installed into the 8GeV S-band Linac.

T. Obina (KEK): Beam Instrumentation for the Compact ERL at KEK

Takashi provided a description of the KEK compact ERL that is presently under construction. Commissioning is planned to start in 2013. They will begin commissioning and beam tests with the gun, injection, rf cavity, and dump. Initial energy recovery operations will have a single loop at 35MeV, with a goal of 10mA. Then an rf cavity upgrade will increase the energy to 65MeV. Later a second loop is planned at 125MeV.

The standard beam diagnostics include stripline BPMs with custom processing electronics, transverse profile measurements using OTR and scintillator screens, synchrotron radiation monitors, streak camera, fast gate camera, beam loss monitors (PMT and/or Fiber) and a machine protection interlock system. Also in the design are wire scanners, and absolute and differential beam current monitors.

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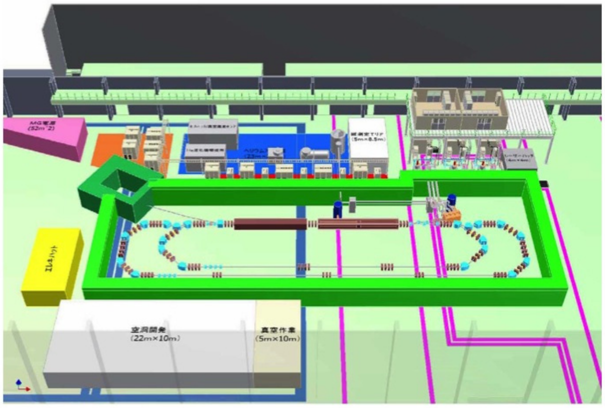

Figure 6: 3D Model of the KEK Compact ERL construction hall.

Special beam diagnostics include a bunch arrival monitor with precise timing distribution, deflecting cavity for longitudinal profiles and longitudinal phase space measurements, high-resolution resonant cavity BPM (low current only), and a beam halo monitor.

The purpose of the compact ERL at KEK is to demonstrate ERL accelerator technologies, the experimental possibilities based on CSR of THz radiation, and a laser inversed Compton X-ray source.

D. Gassner (BNL): BNL Energy Recovery Linac Instrumentation

The ERL project at BNL is currently under construction; first electron beams are planned for later in 2012. Energy recovery operations are expected with high intensity beams that have current up to a few hundred milliamps, while preserving the emittance of bunches with a charge of a few nC produced by a high current SRF gun. To successfully accomplish this task the machine will include beam diagnostics that will be used for accurate characterization of the beam phase space at the injection and recirculation energies, transverse and longitudinal beam matching, orbit alignment, beam current measurement, and machine protection. The distribution of instrumentation is shown in Figure 7.

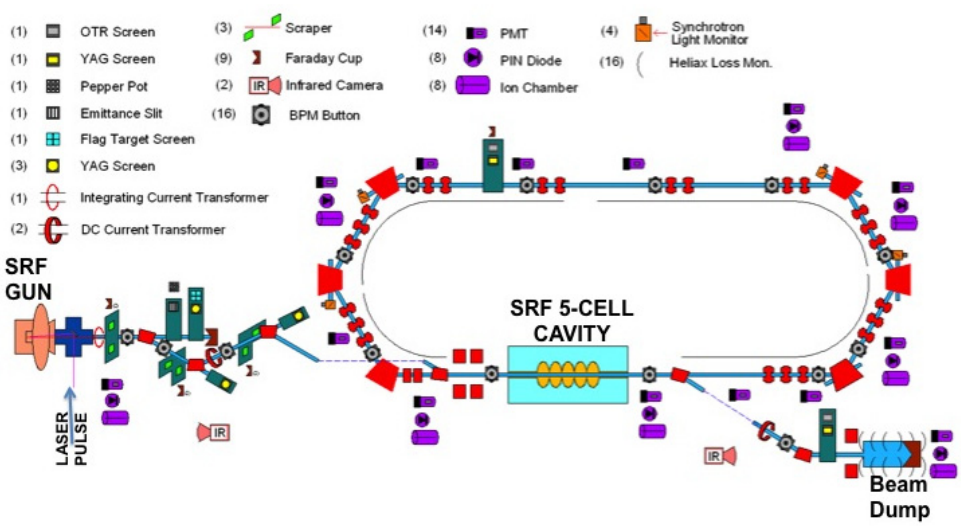

Figure 7: BNL ERL instrumentation layout.

This presentation described the present status of the diagnostic systems that will be used to meet these goals, as well as the sequence of commissioning phases planned to progress from initial gun characterization, to injection zig-zag chicane testing, to closing the beam transport loop and operations that achieve energy recovery.

DISCUSSIONS

Together with working group 5 (Unwanted Beam Loss), discussions were held after each parallel session talk, and later at dedicated discussion sessions.

A question was raised with regards to the vulnerability of the beam current transformer ceramic gaps to charge build-up in high power CW machines with short bunches, and if a metalized coating should be applied to bleed off charge to avoid possible damage and vacuum leaks. This is a concern since many of the ERLs under development plan unprecedented high power CW operations. One risk that was mentioned is the possibility of the coating flaking off and migrating into a nearby SCRF cavity and causing a high gradient point. Shortly after the workshop it was decided to raise this topic with Julien Bergoz [1] who provides many of the CTs in use today. His conclusion was that he is not aware of any conclusive situation where damage to a ceramic break was caused by charge build-up due to the operating beam conditions. His experience is based on the deployment of several hundred CTs (FCT, ICT, NPCT, ACCT) installed in CW machines. At DESY [2] a metalization layer is sometimes applied to the ceramic of the current transformers at DESY, but it does not cover it completely. A thin gap is

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left unmetalized to minimize the high frequency, high-order modes from coupling to the toroid. There were never any reported problems with suspected charge build up on any DESY current transformer ceramics.

There were discussions about measurement of dark current from SRF Cavity field emission and how to distinguish it from beam halo. More simulations would benefit the effort of trying to reduce the detrimental effects of each. It was proposed that some systematic measurements and experiments be conducted to quantify and characterize dark current and halo in operating facilities. This would assist future facilities proposing a significant increase in beam current and power to better design suitable collimation systems, and other mitigations of these issues.

There were discussions about possible methods to measure interleaved electron bunches of different energy on either side of the ERL RF cavity. This remains a challenge to the diagnostics community; it is complicated by the wide variety of bunch spacing parameters and accelerating rf frequencies specific to each ERL. The fast switch described by M. Tobiyama [3] might be a good candidate for specific ERL running modes.

Another topic was the feasibility of using a pair of NPCTs in differential mode to measure ~1uA of lost beam in an ERL. Concerns were raised about the variable bunch train lengths and intensity, bunch train gap lengths, as well as noise coupling to the signal. It was mentioned that the resonant cavity current comparison system used at CEBAF likely performed better that the PMT based BLM system, and better than their DCCT system.

The topic regarding better ways to measure electron bunch lengths was raised. The microwave spectrometer using coherent transition radiation was suggested [4].

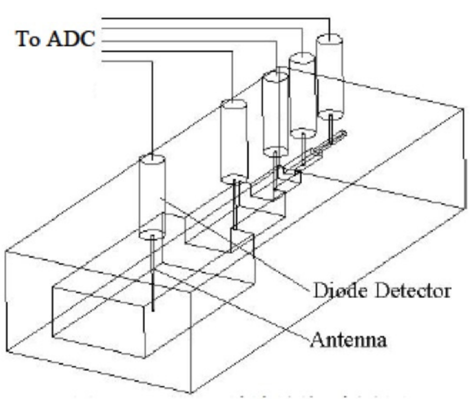

Figure 8: Microwave Spectrometer detector using coherent transition radiation for bunches <10ps.

There were discussions about loss monitor detector limitations and performance and how these aspects apply to Energy Recovery Linacs for machine protection and tuning. It was mentioned that fiber optic cable type BLM detectors are not good candidates for CW machines due to likely radiation damage because of problems after a few MRads. Also, it is difficult to determine the specific time of a loss with a cable of significant length in this case. There were concerns that PMT type detectors might saturate in a sudden very high radiation field, and not send enough signal power to interlock the machine. This was determined to be speculation and would need testing to confirm.

There were discussions about the use of halo scrapers with electron beams, and their possible detrimental effects. The effort to measure the amount of collected electrons from a passing bunch that are intercepted by a variable position scraper jaw is typically not useful since the image charge induced on the isolated jaw is usually on the same order or larger than the signals from the collected electrons. It is difficult, if not impossible to differentiate these two signals.

CONCLUSIONS

We had a plenary presentation on operational performance, experience, and future plans at the existing ERL injector prototype at Cornell. This included instrumentation data, controls system configurations, as well as description of future needs. This was followed by four talks from KEK and RIKEN/SPring-8 that described electron beam instrumentation already in use or under development that can be applied to ERL facilities. The final talks described the ERLs under construction at KEK and BNL. The format of having joint sessions with working group 5 was beneficial as there were a significant number of common topics and concerns with regards to the causes of beam loss, instrumentation hardware, and techniques used to measure and analyse beam loss.

ACKNOWLEDGMENTS

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REFERENCES

[1] Private communication with Julien Bergoz.
[2] Private communication with Kay Wittenburg.
[3] Tobiyama, M. “Turn-by-Turn Monitor using a Fast Gate Switch”, these proceedings.
[4] Maesaka, H., et al. “Development of the Microwave Spectrometer for the Bunch Length Measurement using Coherent Transition Radiation at the SCSS Prototype Accelerator”, Proceedings of the 3rd Annual Meeting of Particle Accelerator Society of Japan and the 31th Linear Accelerator Meeting in Japan (August 2-4, 2006, Sendai Japan), WP20.

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