BEAM DIAGNOSTICS FOR THE STORAGE RING OF THE cSTART PROJECT AT KIT

D. El Khechen*, E. Bründermann, A. Mochihashi, M.-D Noll, A. Papash, R. Ruprecht,
M. Schuh, P. Schreiber, J.L. Steinmann and A.-S. Müller,
Karlsruhe Institute of Technology, Karlsruhe, Germany

Abstract

In the framework of the compact STorage ring for Accelerator Research and Technology (cSTART) project, which will be realized at Karlsruhe Institute of Technology (KIT), a Very Large Acceptance compact Storage Ring (VLA-cSR) is planned to study the injection and the storage of 50 MeV, ultra-short (sub-ps) electron bunches from a laser plasma accelerator (LPA) and the linac-based test facility FLUTE. For such a storage ring, where a single bunch with a relatively wide range of bunch charge (1 pC - 1000 pC) and energy spread (10^{-4} - 10^{-2}) will circulate at a relatively high revolution frequency (7 MHz), the choice of beam diagnostics is very delicate. In this paper, we would like to discuss several beam diagnostics options for the storage ring and to briefly report on several tests that have been or are planned to be realized in our existing facilities.

INTRODUCTION

A lot of R&D studies nowadays are being conducted on new ideas and technologies for future light sources. In this context, KIT plans to build a large acceptance storage ring to demonstrate the injection and storage of ultra-short and LPA-like electron bunches. The research and studies on this project will be exploited for the development of the infrastructure and technology for compact LPA-based future light sources.
The cSTART project (see Fig. 1) employs two different injectors, which will provide ultra-short bunches: the KIT photo-injector FLUTE [1] and an LPA injector [2]. The electron bunches will be transported from the two different electron sources to the storage ring at 3 m height via a transfer line [3]. The storage ring consists of four double-bend-achromat (DBA) arcs with 45° bending magnets [4], separated by four straight sections, amongst which two have space available for one RF station per section, one section will be dedicated for the injection and the other one for beam diagnostics. The magnetic elements in the arc are very close to each other and might be realised e.g. as solid blocks (adopting the MAX-IV magnetic design [5]), leaving nearly no space for beam diagnostics in the arcs. This along with other bunch parameters, e.g. bunch charge, bunch length, repetition rate (see Table 1), bring some challenges when choosing the type and the design of diagnostic tools in the arc, and impose high-standard requirements on dynamic ranges and electronics. In this paper, we will give an overview of the most important beam diagnostics planned for the cSTART storage ring and highlight the challenges of some existing designs. Furthermore, we will point out few experimental tests which are and will be taking place at our KIT facilities to test some of these diagnostics.

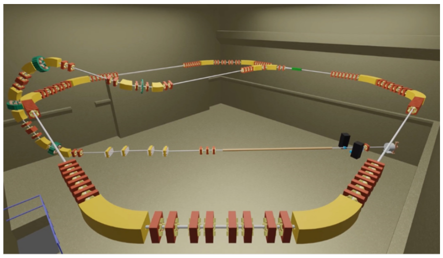

Figure 1: A 3D artistic view of the whole cSTART project: sextupoles and octupoles and the LPA injector are not included, courtesy to J. Schäfer

Table 1: Important Beam Parameters of the cSTART Storage Ring

Parameter	Value
Operation mode	single bunch
Energy	50 MeV
Revolution frequency	7 MHz
Bunch charge	1 pC to 1000 pC
Bunch length	10 fs to 1000 fs
Momentum acceptance	± 5.5%
SR losses/turn	< 1 eV
Energy spread	0.01% - 1%
Lifetime	from 100 ms to 10 s

A DESCRIPTION OF THE DIFFERENT DIAGNOSTICS TOOLS

In the very first stages of running a new machine, many unknowns will be encountered. The very important role of the beam diagnostics tools is to unmask the conditions of the machine and to help improve the operation efficiency. Within the project, we aim to perform turn-by-turn, as well as bunch-by-bunch, measurements of the beam parameters. In this section, we will discuss mainly the most important beam diagnostics tools for early stage commissioning and we will comment on the challenges of their application and design.

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[*] dima.khechen@kit.edu

Beam Position Monitors

With beam position monitors (BPMs) we aim to measure the beam position with a precision better than 100 µm to be able to store LPA-like electron beams. Different BPM tools are available on the market but not all of them fit to the cSTART requirements. In the following, we discuss a hybrid BPM system based on striplines and button BPMs for the storage ring. Concerning cavity BPMs, although they acquire the best position sensitivity and resolution, we excluded them for two reasons:

- They cannot fit between magnetic elements in the arc sections as they need a space of at least 30 cm
- Given in a storage ring, they might induce wakefield issues/problems and subsequently undesired bunch instabilities.

Stripline Pickups At cSTART, the incoherent synchrotron radiation (SR) is negligible given the low beam energy of about 50 MeV. This allows the possibility of integrating stripline pickups inside quadrupole magnets without caring about heat load from SR on the strips. In this context, we plan to install at least ten striplines inside quadrupoles in the arc sections. The length of the striplines will be equal to that of the quadrupoles, in the order of 8 cm. The design of the striplines will be adopted from that of the FLASH Linac at DESY[6], where strips will be hidden between the poles of the quadrupoles. It is very important not to reduce the physical aperture of the beam pipe in order to store as much as possible of the large emittance beams ($\epsilon_x = 10\,\mathrm{nm\cdot mrad}$). Furthermore, the bellows (6 cm length) at the adjacent sides of the stripline in the FLASH design cannot be realised in the case of cSTART given the lack of space. These bellows are important to align the stripline and the quadrupole and to compensate for thermal expansion and contraction of the whole beampipe (for example during the bake-out procedure), thus controlling the mechanical stress on the striplines. In this case, we plan bellows somewhere else in the arcs to control the mechanical stress on all the components relying on non-drifting stripline-quad offsets through a solid mechanical design.

Button BPMs The space between the magnetic elements in the arc, when exists, will be exploited for the insertion of bellows and vacuum components, this won´t allow the installation of any button BPM. Two to four button BPMs will then be installed in every straight section. The button BPMs developed for the European XFEL [7][8] provide a resolution ≤ 50 µm at a bunch charge of 20 pC with repetition rates of 4.5 MHz. This makes them potential candidates in addition to their adequate mechanical design, which allows fitting them in the very narrow space in the arcs.

Current Monitors

Bunch charge measurements are very important especially during the commissioning phase. For this reason, we plan to install fast current monitors in the straight sections. The turbo-ICTs along with their BCM-RF readout electronics, from Bergoz Instrumentation [9], are very sensitive (optimised for very low bunch charge > 50 fC) with a very good resolution down to 1% of the single bunch charge. However, the existing version of the system only provides single bunch charge measurements at repetition rates ≤ 2 MHz. This means, using the existing turbo-ICT design, we will not be able to resolve bunch charge every turn but we can integrate it over three turns. Further R&D on the readout electronics is needed to be able to resolve the bunch charge every turn. The time resolution of the charge measurement can be improved by utilizing the BPM sum signals.

Beam Loss System

For beam loss measurements, we have thought of scintillation detectors as they are very sensitive. We are considering scintillator materials connected to photomultiplier tubes (PMT) or scintillation fiber optics routed around the ring. Hereby, we need to consider their different positioning, sensitivity and feasibility.

Scintillator with PMT The compact design and adequate dimensions of this system makes the scintillation detector a good candidate for a beam loss monitor at cSTART. These detectors are readout with Libera-BLM electronic units [10] and are able to detect fast losses (injection losses, etc.), and slow losses (Touschek scattering, beam-gas bremsstrahlung, etc.), in addition to many other interesting and useful features (postmortem buffers, ADC mask, etc.). These scintillators with PMT will be distributed at places with high dispersion functions (mainly next to bending magnets and sextupoles) where high losses are expected. In the arc sections, the detectors could be placed inside or outside the solid block of magnets, while being outside might risk the absorption of all the electromagnetic shower from the lost electrons in the block material (simulations are in progress). One concern about this system is its calibration, which should be done with either a radioactive source (see Fig. 2) or an LED, and should take the cable length into account.

Scintillating Fiber Optics The scintillating fiber optics were used as a multi-purpose beam diagnostics tool (beam profile measurements [11], beam loss, etc.) and they have proven their reliability. These fibers could be stacked in bunches to increase the sensitive area and then attached to the beam pipe directly, covering all the ring if necessary. This brings a great advantage when unpredictable losses happen in unforeseen positions (obstacles, orbit bumps, etc.). In our case, simulations using FLUKA are taking place to study the beam loss signal in such fibers. After that, a decision on the number of fibers needed along with the scintillating material and its thickness can thus be taken.

Figure 2: A scintillator detector (without the lead shield) being calibrated with ^{137}Ce radioactive source at the KARA storage ring

Longitudinal Profile Measurements

So far, we plan an electro-optical spectral decoding (EOSD) system for longitudinal profile measurements. This could be a near-field EOSD [12, 13] or a far-field EOSD [14] setup, similar to what we use at the Karlsruhe Research Accelerator (KARA). This system so far provides temporal resolution in the range of tens of fs and R&D is going on to improve the resolution down to few fs [15]. At the cSTART storage ring, both setups for longitudinal profile measurement could be used. The far-field setup can be placed at one of the planned optical beamlines next to the bending magnets in the arcs and the near-field setup will be placed in the diagnostics straight section.

Screen Monitors

Several screen monitors will be distributed around the ring, mainly in the straight sections (where space allows) close to the entrance and exit of the arc sections. These consist of motorized mechanical arms holding a standard fluorescence screen, a mirror and a CCD camera. The screen monitors help in case of difficulties storing the beam, to know at which stage/position in the storage ring the beam is lost. In addition, they help define the beam transverse profile as a step to optimising it by tuning the magnets in the arc.

EXPERIMENTAL TESTS AT THE KARA ACCELERATOR

An upgrade of the beam diagnostics system in the booster synchrotron and the KARA storage ring of the KIT Light Source takes place. This will be exploited, especially in the booster where the beam energy and revolution time is comparable to the storage ring of the cSTART project, to test if features of the diagnostics tools are consistent with the requirements. In this sense, development of bunch-by-bunch and turn-by-turn readout electronics for bunch charge and beam position in the booster is taking place, using the sum signal of a button BPM and a stripline. Furthermore, a new beam loss system based on Hamamatsu scintillators with PMTs is being installed, calibrated and tested in KARA. Furthermore, a near-field and a far-field (at the IR2 beamline) EOSD setup are in operation and in commissioning, respectively, at KARA. In addition, an upgrade of the booster diagnostics including the installation of a bunch-by-bunch (BBB) feedback system, a transverse and longitudinal beam profile measurement setup [16], will reveal beam dynamics in the booster that will be used to predict expected behaviours in the cSTART storage ring.

SUMMARY

The choices and challenges of choosing a beam diagnostics system for the unique parameters of the cSTART storage ring have been discussed. The design of some already existing tools will be adopted. In addition, further measures will be taken to adapt it to the requirements of the storage ring in the cSTART project, e.g. for the repetition rate in the MHz range. The ongoing and planned experimental tests with the upgraded beam diagnostics systems at the KIT accelerators will deliver results on the expected behaviour of beam diagnostics tools suitable within the cSTART project. Furthermore, studies and simulations are in progress to understand and decide on the beam diagnostics tool set for the KIT-project cSTART.

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