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VSR INJECTOR UPGRADE AT BESSY II

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Abstract

BESSY VSR is a fully funded project at the Helmholtz-Zentrum in Berlin (HZB). The objective is to produce simultaneously both long and short pulses in the storage ring. The implications for the existing injector systems and the upgrade strategy are presented in this paper. Envisaged is a global upgrade which includes additional accelerating structures to reduce the bunch length in the booster, more flexibility in the filling pattern, online orbit measurements and implementing longitudinal feedback.

INJECTION AT BESSY VSR

A comprehensive description of the injection system at BESSY II was recently given in [1]. In a familiar fashion that characterized 3rd generation light sources across the world, injection into the storage ring is from a low energy linac followed by a full energy booster synchrotron.

Although the present injection scheme is highly reliable, a global upgrade is foreseen for the BESSY VSR project [2]. The most prominent aspect with respect to the injector is the evidence that the bunch length on injection into the storage ring needs to be reduced from its present value, by at least a factor two in order to keep the high injection efficiencies. The problem arises from the large difference in the bunch lengths on injection and the reduced phase acceptance in the short buckets due to the proposed VSR technique shown in background of Fig. 1.

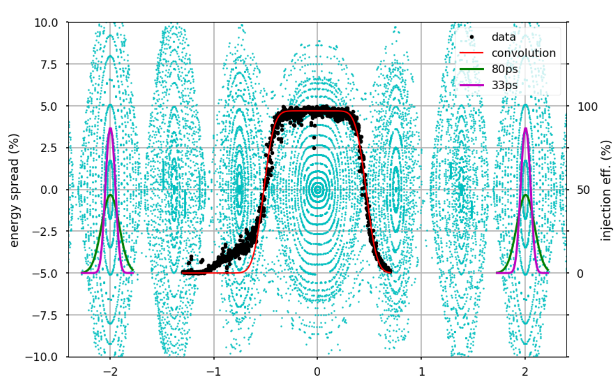

Figure 1: Longitudinal acceptance in the VSR mode. In the background the simulated BESSY VSR phase space. The foreground shows present injection efficiency data at BESSY II with respect to a phase offset, a simple convolution fit of the data and injection efficiency predictions for shorter pulses.

The injection efficiency data shown in Fig. 1 was found as a function of phase delay between the booster and storage ring. These scans are to determine the phase acceptance of the present BESSY II buckets. The longer buckets in the VSR mode will be equivalent to the present 500 MHz RF setup and therefore can be readily used study future VSR modes. The red curve is a convolution of a Gaussian (bunch) and flat top (bucket), here the 1D model assumes no transverse effects. The fit suggests the present injected bunch is at maximum 80 ps long. The green curve is the prediction for the short buckets in BESSY VSR assuming this present condition. Here injection efficiencies of only 50% are expected. The cyan curves show the increase in injection efficiency up to 90% when shorter bunch lengths of 33 ps in the booster are assumed.

Extensive machine commissioning studies have found key parameters both in the booster and storage ring which can be optimised to broaden the injection plateau and make full use of all the phase space available [3]. The constraints on the injection efficiency for VSR: single shot >60% and 4 hr average >90% defined by our radiation officer are demanding but need to be respected. These constraints motivate the upgrade scenarios described in the rest of the paper.

UPGRADE OF RF SYSTEMS

The preferred method to produce shorter bunches from the booster is an upgrade of the existing 500 MHz RF system. Presently there is a single 5-cell PETRA cavity installed in the booster. A 40 kW transmitter is used to deliver a ramped cavity voltage to 400 kV during the 10 Hz booster cycle. The cavity itself can operate with double the power but such an installation is not available at present. The procurement of additional transmitters is necessary for any upgrade scenario. Starting from a status quo, an abundance of applicable scenarios were investigated such as the use of 80 or even 100 kW transmitters, with it the appropriate waveguide structures and additional cavities. Options including installing more 5-cell PETRA cavities, switching to EU-HOM damped cavities or altering the base RF to cavities of higher harmonics were also investigated. With each suggestion a goal function of cost effective shortening factor per M€ was calculated to ease the comparisons. The cost estimates were found from market research and in-house expectations.

In order to reduce the bunch length by a **factor of 2**, two additional 5-cell PETRA cavities each driven by 80 kW transmitters are necessary, as given in Table 1. This scenario is also appealing to the BESSY II machine group as it involves the procurement and installation of known components. In terms of beam commissioning, slowly increasing the total RF gradient by operating the additional cavities one after

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Table 1: RF Upgrade Scenarios for the Booster

5-cell PETRA cavities (#)	1	1	2	2	2	3	3
Power per cavity (kW)	40	100	40	80	100	40	80
RF Gradient factor	1	1.58	2	2.83	3.16	3	4.24
bunch shortening factor	1	1.26	1.41	1.68	1.78	1.73	**2.06**
shortening factor per M€		1.48	2.09	1.72	0.89	1.28	1.06

another, is a subtle way to actively control and diagnose the beam in all dimensions.

A CSR threshold was estimated for the booster using parallel plate shielded CSR-impedance theory [4] for the dipole vacuum chamber:

$$\frac{N r_e}{2\pi \nu_s \gamma \sigma_E} \frac{\rho^{1/3}}{(c\sigma_0)^{4/3}} \geq 0.5 + 0.12\, c\sigma_0 \sqrt{\frac{\rho}{h^2}} \tag{1}$$

For the relevant beam parameters: zero current bunch length $\sigma_0 = 30\,\mathrm{ps}$, energy spread $\sigma_E = 6{\cdot}10^{-4}$, bending radius $\rho = 6.67\,\mathrm{m}$, half plate separation $h = 15\,\mathrm{mm}$, tune $\nu_s = 0.032$ and $\gamma = 3366$ the CSR threshold charge limit lies by 15 nC. At half the bunch length the charge limit is still a magnitude larger than the linac is capable of. However, if the bunch length was reduced by a factor 3 or 4, then CSR would become a dominating effect.

5-cell PETRA cavities such as those proposed here, were developed without supplementary features to reduce unwanted HOMs. Installing such cavities will lead to higher ring impedance and enhance the longitudinal instabilities resulting in a larger effective emittance of the multi-bunch injection that we already witness in the booster [1]. The next section introduces the suitable device intended to combat these supplementary problems.

LONGITUDINAL KICKER CAVITY FOR THE BESSY II BOOSTER

The use of overloaded cavities and active feedbacks to compensate longitudinal instabilities at both the BESSY II and MLS storage rings is long established. The last comprehensive publication [5] detailed the excellent performance at both storage rings and the additional bunch-by-bunch features the beam users could take advantage of. The cavity hardware presently installed was first commissioned almost two decades ago. Since the first design in 1995 at $DA\Phi NE$ [6] the overloaded cavity has been modified and optimised to suit most 3rd generation light sources across the world. The base design for the longitudinal kicker to be installed in the booster to mitigate instabilities and help multi-bunch injection into the storage is that recently used at Diamond Light Source (DLS) [7]. This design is an amalgamation over the years of high end computer simulations and multi-objective optimisation to produce a low-Q, broadband device with little impedance at high frequencies suitable for modern storage rings.

To date no such longitudinal kicker exists in the BESSY II booster. Numerous active feedback attempts have used a simple transversal stripline kicker installed in a dispersive sector, connected so as to couple to the longitudinal plane. A proof-of-principle of active damping during the ramped acceleration was successful. Towards the end of the ramp when the synchrotron tune is stable, the feedback was effective but limited due to the power amplifier. With these findings and the proposed RF upgrade, a longitudinal kicker cavity for the booster is under development.

Fig. 2 introduces the general design modifications from the DLS baseline. Notably the beam pipe in the booster straight is round, and not tapered like in modern storage rings. The optimisation process uniformly scales the cavity components for a fixed beam pipe dimension. To maintain the coaxial cross section, the couplers are translated accordingly. The resulting cavity design is then dependent on this scaling parameter s.

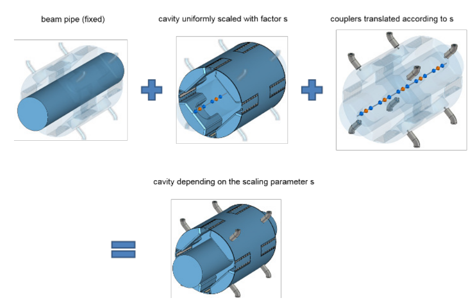

Figure 2: CST has been predominately used to scale the DLS baseline design to match the characteristics of the surrounding booster systems.

This scaling parameter so far has shown great promise, the DLS baseline design has been scaled down in frequency towards 1.625 GHz. The optimisation process is still ongoing to find a solution to restore the 250 MHz bandwidth and ease installation in the booster vacuum systems.

FLEXIBLE INJECTION INTO THE STORAGE RING

The low injection efficiency problematic described in the first section of this paper; highlighting the reduced longitudinal acceptance of the storage ring for short buckets in BESSY VSR, could be greatly relaxed if the pulse pattern from the injector systems was more flexible. Presently the TimerUnit (part of the original linac installation) that produces the pulses to be amplified on the electron gun cathode driverboard is only capable of fixed separation and pulse charge. Identical single bunch pulses constitute for the multi-

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bunch regime commonly used in TopUp at BESSY II. Although the global separation is programmable individual pulse separation is fixed as shown in blue in Fig. 3.

Foreseen is an upgrade towards a fully programmable regime expanding over a single extraction kicker pulse of 320 ns. Both the separation and amplitude of each pulse needs to be freely programmable. Tests to realize this installation have been undertaken at the GunTest stand at HZB. Here an identical electron gun as used in the linac tunnel has been constructed to keep as a warm spare part and aid investigations on the electron source.

The low level signals generated within the TimerUnit could be replicated using a stand alone digital delay generator. The freely programmable electrical pulses from the generator were then converted to light signals (through bypassing the TimerUnit circuitry but using the Transceiver) and sent to the cathode driverboard via fibre optics.

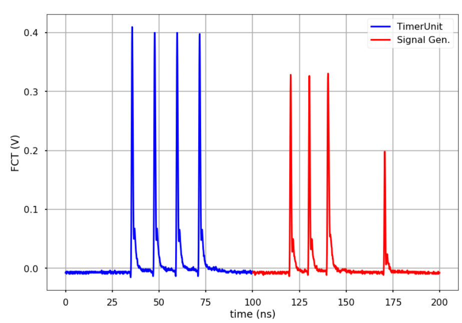

Figure 3: Electron bunch pulse structure as observed on the Fast Current Transformer (FCT) in the HZB GunTest stand.

Fig. 3 compares the electron bunch pulse structure produced via the existing TimerUnit and the freely programmable signal generator. The pulses shown in red, have been chosen to mimic the VSR fill pattern. The cathode driverboard was found to function beyond the original expectations. The separation, charge and pulse length are free to chose. One can envisage from the pattern shown in red, that the highly efficient multi-bunch (MB) and the less efficient short-bunch (SB) modes could be filled in one single TopUp event:

$$\frac{N_{\mathrm{MB}} \cdot 95\,\% + N_{\mathrm{SB}} \cdot 50\,\%}{N_{\mathrm{MB}} + N_{\mathrm{SB}}} \geq 60\,\% \qquad (2)$$

This mimic will keep the single shot efficiency over 60%, allow for more flexibility in the fill pattern and may even help the Touschek [8] lifetime in BESSY VSR.

LIVE BPM DATA IN THE BOOSTER

As recently introduced [9], a cost effective Beam Position Monitor (BPM) diagnostic was built around the data acquisition capabilities of the Red Pitaya. The FPGA firmware and the board support package of the system were modified such that a simple DMA scheme is used to store the data in a 128 MB continuous part of the DDR3. With a relatively simple C program to configure and control the data acquisition that is initiated in response to an external trigger one can store up to 32 million samples for each input channel. This allowed a full resolution with no decimation (125 MS/s) data acquisition over the entire 10 Hz booster ramp.

With its present parameters and optic, such extensive acquisition in the booster is not entirely necessary. The interest of this versatile diagnostics has shifted to archiving the slow drifts in beam dynamics through the injector systems. Fig. 4 compares a long term beam position with the average current per bunch in the booster. Over the course of days, the parameters of multiple injector components such as the HV power supply for the linac klystron, numerous phase shifters and the general climate in the booster tunnel drift away from the optimised solution reducing the beam current in the booster. This additional diagnostic is now setup to measure and evaluate the rate of deviations in orbit position and aid the machine operator during readjustments.

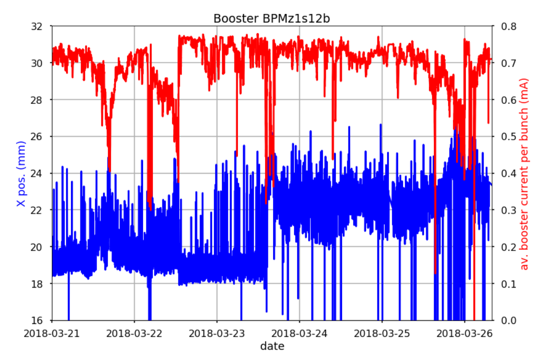

Figure 4: Archived orbit position at a BPM and the average current per bunch in the booster.

OUTLOOK

An upgrade of the RF systems to install two additional cavities into the booster has been chosen in order to reduce the bunch length by a factor of 2. Reducing the bunch length will help ease the high injection efficiencies into the storage ring. A longitudinal cavity is under development using a well established baseline design to mitigate unwanted beam effects caused by these additional accelerating cavities. Generating a more flexible fill pattern in the injector shows great promise. Archived BPM acquisition in the booster is online to evaluate slow drifts within the injector systems.

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