SINGLE ELECTRON EXTRACTION AT THE ELSA DETECTOR TEST BEAMLINE

F. Frommberger, N. Heurich, W. Hillert, T. Schiffer and M. Switka
ELSA, University of Bonn, Germany

Abstract

The electron pulse stretcher facility ELSA delivers polarized and non-polarized electrons with an adjustable beam energy of 0.5 - 3.2 GeV to external experimen tal stations. Extraction currents available range down from 1 nanoampere to several attoamperes. Especially the high energy physics community requires detector test stations with electron tagging rates between 1 kHz–100 kHz, imposing particular requirements for stable low-current extraction from the storage ring. These requirements are met with the implementation of a low-injection mode for the booster synchrotron and photomultiplier-based stored current monitoring, providing feedback for a selectable limit of the stored current down to nanoamperes. A homogeneous extraction with duty factor > 80 % is routinely granted by the excitation of a 3rd integer optical resonance. The setup of the low-current injection system and the exctraction properties at the preliminary extraction beamline are presented.

INTRODUCTION

The electron stretcher facility ELSA [1] (see Fig.1) is an accelerator facility consisting of three stages: In one of the two LINACs electrons are accelerated to 20 or 26 MeV, resp., and then injected into the second stage, a fast cycling booster synchrotron with cycle time of 20 ms.

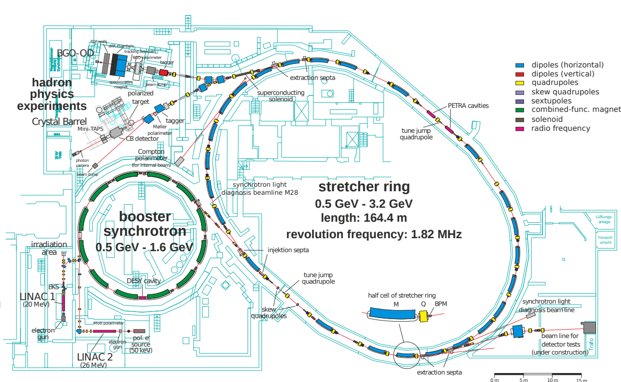

Figure 1: Layout of the ELSA facility.

In the booster synchrotron the electrons are typically accelerated up to 1.2 GeV and then transferred into the third stage, the stretcher ring. In the stretcher ring several injections from the booster synchrotron are accumulated and subsequently a post-acceleration to a maximum energy of 3.2 GeV is possible. From the stretcher ring the electrons are extracted during 4 − 6 s to one of the hadron physics experiments CBELSA/TAPS [2] or BGO-OD [3] via slow resonance extraction. Typical external currents for the hadron physics experiments are 0.5 − 1.5 nA.

In the last years an increasing demand for beam-time for the testing of pixel detector prototypes appeared. These pixel detectors are designated for the use in high energy physics experiments (e.g. upgrade of ATLAS detector at CERN).[1] In these tests the detectors are irradiated directly by the extracted electron beam. The maximum possible counting rate of these detectors is 200 kHz/cm^2, but depending on the trigger conditions even lower rates are necessary. These demands make the stable extraction of very low currents < 1 pA necessary. At the moment the commissioning of a new detector test beamline is underway [4], but in the last two years beamtimes under these conditions have already been carried out in one of the hadron physics areas.

The tested detectors are used for tracking and therefore consist of several layers of pixels. To reduce multiple scattering[2] and hence to allow a better position resolution and tracking, the tests are always carried out the highest possible energy of ELSA.

ULTRA-LOW CURRENT MEASUREMENT

In order to grant controllable low intensity extraction it is necessary to measure and reliably limit the stored electron current. The detection of visible synchrotron radiation (SR) emitted from the stored electrons is the backbone of this operation mode as sensitive optical devices, such as photomultipliers with measurement capabilities down to the single-photon counting regime, are utilizable.

ELSA's synchrotron radiation monitor *M28* is used to guide the visible SR component out of the shielding tunnel into an optics laboratory using a ∼30 m long multimode glass fiber cable. The optical path is illustrated in Fig. 2.

A water-cooled pick-off mirror with an area of 1×2.8 cm^2 accepts the full SR load and deflects the visible component into an optical box. The beam is focused by an $f = 500$ mm lens (magn. $M = 0.125$) onto the fiber coupler with aperture $D = 19$ mm. As orbit displacements and subsequent photon beam displacements affect the coupling efficiency of the fiber, the coupler is set onto a motorized three-dimensional stage which is remotely controlled in order to find the optimum position for maximum intensity transfer. For photon beam position control, a narrow band dichroic beam splitter reflects the blue SR component onto a CCD camera. It is also used for redundant intensity measurements and functions as high current safety threshold detector.

[1] When the new detector test beamline is in operation, it also planned to test detectors for BELLE II at KEK.

[2] The mean deflection angle is for high energy electrons $\sim \frac{1}{E}$.

ISBN 978-3-95450-147-2

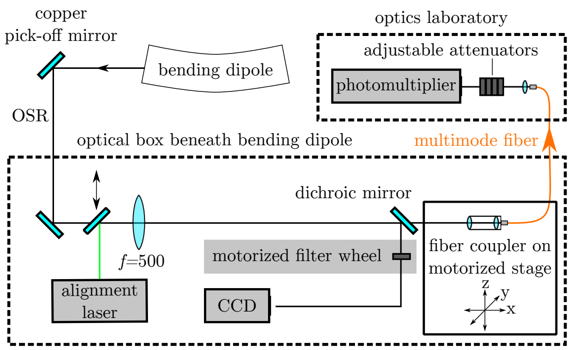

Figure 2: Layout of the M28 visible synchrotron radiation beamline with fiber connection to an optics laboratory.

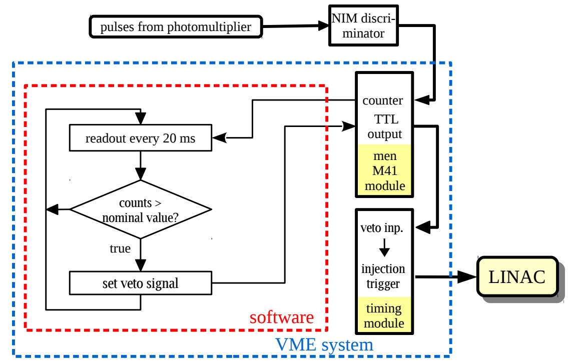

Figure 3: Scheme of the storage ring's injection control.

In the optics laboratory the outcoupled SR is refocused onto the photocathode of the photomultiplier. The device in use[3] was available from a decommissioned hadron physics experiment and features a gain of 10^8 at 2.3 kV supply voltage. An optical neutral density filter attenuator array is inserted to increase the dynamic range of the photomultiplier towards high electron currents. This allows for approximate callibration with with the standard current monitors. Featuring a sensitivity of $\sim$ 85 counts/nA within a typical 20 ms binning cycle, its detection threshold of stored beam is five orders of magnitudes lower compared to the facility's capacitive or inductive beam monitoring diagnostics.

INJECTION

In order to reliably fill the stretcher ring up to nanoamperes, the intensity of the electron current in the booster synchrotron is strongly reduced by decreasing the booster RF power below 100 W. Usually the electron current in the stretcher ring is measured by a current transformer[4]. Due to the noisy environment where this instrument is installed, it cannot be used for monitoring currents below the milliampere range. Therefore the signals from the photomultiplier are digitized by a discriminator and the digital pulses are sent to a counter in a VME system. The data from this counter is read every 20 ms, corresponding to the cycle time of the booster synchrotron. In the timing system of the accelerator a maximum number of injections from the booster synchrotron per accelerator cycle is preset. When the number of counts exceeds a given threshold, further injections from the booster synchrotron are automatically switched off (cf. Fig. 3). Assuming that the pulse rate from the photomultiplier is proportional to the electron current, this scheme allows a stabilization of the current in the stretcher ring.

In Fig. 4 the measured synchrotron radiation from the beam in the stretcher ring is shown for one accelerator cycle. Each point shows the value of the counter integrated over 20 ms. The threshold for the switch-off of the injection was set to 5000 counts. The picture shows that this threshold was already exceeded after the 2nd injection (see detail of injection phase on the left side of Fig. 4). Due to the fact that the value of the counter is read after the end of an injection from the booster synchrotron it is not possible to switch off the injection immediately when the threshold is reached.

To achieve an additional long-term stabilization of the injected current, a lower and an upper limit for the number of injections per accelerator cycle is defined. On the accelerator's control computer a program is running which automatically increases or decreases the RF power in the booster synchrotron if the number of injections is outranging the limits (cf. Fig. 5).

When the injection phase is finished, a damping phase follows in which beam oscillations are damped due to SR emission. After that the beam is accelerated to its end energy, which is for detector tests always 3.2 GeV.[5]

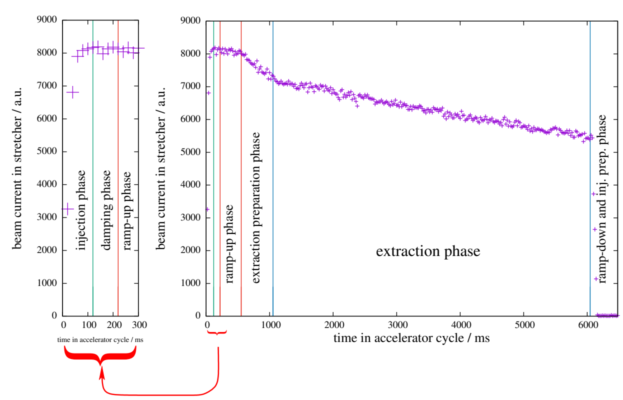

Figure 4: Photomultiplier count rate as measure of stored beam current during one accelerator cycle. On the left side the injection phase is shown in more detail.

Despite of the injection limit it cannot be excluded that for unpredictable reasons a much higher current is injected into the strecher ring than desired. Then a stable extraction of the requested low electron rate would not be possible. To avoid damage of the detectors tested, the current must be dumped before it is accelerated to its end energy. Therefore an interlock software has been developed monitoring certain signals to detect such a condition:

[3] Photonis XP2262 photomultiplier.

[4] Parametric current transformer from BERGOZ.

[5] The usual ramping speed is 6 GeV/s.

ISBN 978-3-95450-147-2

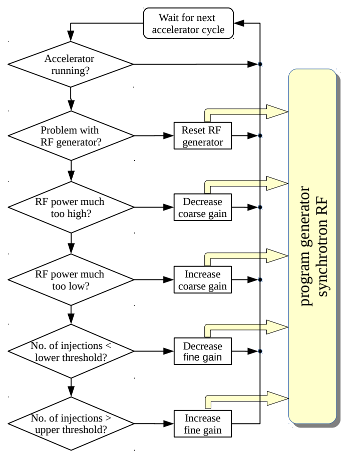

Figure 5: Control of the synchrotron RF generator.

- The signal from the CCD camera at the SR monitor is digitized by a frame grabber and a Gaussian function is fitted to the data. If the height of this function exceeds a given limit, the current in the stretcher ring is considered as too high.
- Analogous and digitized signals from the Bergoz current monitor: If the signal exceeds the noise level the stored current is too high.

The signal from the photomultiplier itself cannot be used as high light intensity results in a breakdown of the high voltage causing a limited or ceasing count rate.

If too much stored current is detected, the computer controlling the RF system in the stretcher ring is programmed to ramp-down the RF power, hereby ensuring that all beam is lost before the extraction phase starts.

EXTRACTION

The electron beam is extracted during several seconds (typ. $t = 4 - 6$ sec) from the stretcher ring using resonance extraction at a third-integer betatron resonance. During the extraction time the horizontal betatron tune is shifted towards the value $4\frac{2}{3}$ by use of 4 air-coil quadrupoles. To ensure a constant current during the extraction time the extracted current is permanently measured and a software PID controller for the currents of the air-coil quadrupoles is used to minimize deviations from nominal current value.

For the hadron physics experiments the extracted currents are in the range from 100 pA up to 1.5 nA. These currents allow the use of resonant cavities for the current measurement. In the low-current mode the rate of extracted electrons ranges from 1 kHz to 1 MHz, corresponding to currents from several tens of attoamperes to femtoamperes. For the measurement of such low currents an alternative set-up was necessary. A thin scintillator equipped with a photomultiplier is inserted into the electron beam. The pulses from this photomultiplier are fed into a NIM discriminator. The output pulses from this discriminator are counted by a home-developed VME counter module. Every 10 ms the data from the counter module is read and a new current value for the air-coil quadrupoles is generated by the PID controller. In Fig. 6 the rate of extracted electrons and the corresponding current of the air-coil quadrupoles is shown for an extracted electron rate of approximately 31 kHz.

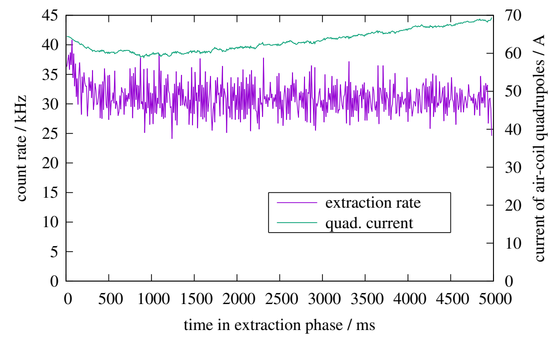

Figure 6: Electron rate (purple) and current of air-coil quadrupoles (cyan) during the extraction phase.

Hence, the mean counting rate is 310 counts in each 10 ms interval. Therefore the statistical fluctuation of the count rate per interval has already a sigma of 18 counts. This effect is responsible for the short-term fluctuations in the electron rate visible in Fig. 6. An external electron rate of 31 kHz means that on average every 59th revolution in the stretcher ring a single electron is extracted into the external beamline.

CONCLUSION

The extraction of single electrons for detector test purposes is granted by slow extraction from an ultra-low stored electron beam current. At ELSA, the injected current is drastically reduced by decreasing the booster RF power. The ultra-low injected and stored beam current is monitored by a photomultiplier whose count rate is proportional to the emitted SR intensity. The regular resonance excitation routine is used to provide a constant extraction beam with electron count rates down to 1 kHz. As low-intensity extractions were successfully performed on a preliminary experimental station, future operations will utilize a dedicated beamline whose operation is expected to start within the year.

REFERENCES

[1] W. Hillert, "The Bonn electron stretcher accelerator ELSA: Past and future", *Europ. Phys. Jour.*, vol. A28, p. 139, 2006.

[2] J. Hartmann et al., "The polarization observables T, P, H and their impact on $\gamma p \to p\pi^0$ multipoles", *Physics Letters B*, vol. 748, p. 212, 2015.

[3] P. Levi Sandri *et al.*, "The BGO calorimeter of BGO-OD Experiment", *J. Phys.: Conf. Ser.*, vol. 587, no. 1, p. 012042, 2015.

[4] N. Heurich *at al.*, "A new external beamline for detector tests", in *Proc. of IPAC'13*, Shanghai, China, May 2013, paper THPFI006, pp. 3300–3302.