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ELSA - ONE YEAR OF EXPERIENCE WITH THE BONN ELECTRON STRETCHER ACCELERATOR

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Abstract One and a half year ago the Bonn ELectron Stretcher Accelerator ELSA came into operation. Since then detailed machine studies have been performed between 0.5 and 2 GeV. The control system proved to be a valuable tool for operating the machine. Injection into ELSA including the fast extraction out of the 2.5 GeV booster-synchrotron has been investigated. The adjustment of dipoles and quadrupoles has been checked by closed orbit measurements. The slow extraction at a third integer resonance has been studied in detail. Extraction times up to 200 msec with a duty factor of about 35 % are possible. For synchrotron radiation experiments the accumulation and storage of high currents up to 275 mA in ELSA was tested. The beam lifetime (1/e point) at 30 mA is in the order of 15 min. (due to vacuum limitations). Since one year the three experiments have been supplied with external beams.

Introduction

The electron stretcher accelerator ELSA is the first continuous beam machine which provides electron beams between 0.5 and 3.5 GeV. As a booster for the stretcher serves the 2.5 GeV electron synchrotron that came into operation in 1967.

ELSA is operated in three different modes. Up to 2 GeV the pure stretcher mode is applied. Immediately after injection from the synchrotron the slow extraction at a third integer tune starts and continuously supplies the experiments until the next injection with electrons. Above 2 GeV ELSA works as a post accelerator. After injection of one or several pulses, the electrons are accelerated to the to the required endpoint-energy (at maximum 3.5 GeV). Then the electrons are slowly extracted at constant energy. The "macroscopic" duty factor depends on the ramping times, the flat top time and the time used for injection and is lower than the duty factor reached in the pure stretcher mode. The third possibility is the use of ELSA as a storage ring for synchrotron radiation. Here up to hundreds of pulses are injected into ELSA and stored. With a circulating current of 30 mA a beam lifetime (1/e) of up to 15 min. has been achieved. To keep a constant high intensity in ELSA we inject from the synchrotron which operates at a repetition frequency of 50 Hz every tenth pulse only. The synchrotron radiation leads to evaporation of surface contaminations from the vacuum chamber, therfore the pressure rises and the lifetime is limited. At 275 mA circulating current - our maximum value observed so far - the pressure increases from some 10^{-9} mbar to about 10^{-6} mbar. We expect that after longer lasting storage runs the cleaning effect will increase the beam lifetime considerably. Details of the machine's design and construction can be found elsewhere[1]. Some relevant parameters of ELSA are shown in the table (the energy dependent values are calculated for 3.5 GeV).

circumference	164.4 m	dipole field strength	1.073 T
# of dipoles	24	energy loss per turn	1.22 MeV
bending radius	10.88 m	mom. comp. factor	6.3 %
# of quadrupoles	32	natural emittance	0.9 mm mrad
# of sextupoles	12	natural energy width	0.09 %
# of extraction quadrupoles	4	revolution frequency	1.82 MHz
harmonic number	274	RF frequency	499.667 MHz

Synchrotron Extraction and Injection into ELSA

Three septum magnets, 3 fast kickers and 3 slow kickers are used for a three turn shaving extraction from the synchrotron. The slow kickers produce a closed bump to shift the beam towards the first septum magnet. The fast kickers then are fired individually at different times (time-steps of 25 ns are possible) to produce an extracted beam over about 600 nsec to match approximately the ELSA revolution time (548 nsec).

Two septum magnets and 3 fast kickers are used for the injection into ELSA. The kickers produce a closed bump for two revolutions in ELSA. The only parameter to be pretended is the bump amplitude at the end of the second septum, the control system inspects the realtime database for the energy, the quadrupole strengths and the strengths of the sextupoles within the bump to automatically calculate and adjust the voltages of septum magnets and kickers. The first three revolutions after injection into ELSA are shown in Figure 1. Whether several shots of the synchrotron are accumulated in ELSA or not depends only on the amplitude of the bump. A switch between stretcher and accumulation mode is thus possible within seconds.

ELSA Control System

The ELSA control system is based on a system of distributed front-end microprocessor modules, connected to the ELSA host computer cluster by two high speed serial links. Each microprocessor module runs dedicated software to control its assigned ELSA device. The host cluster consists of two VAX-750s and one Workstation VAX-3200.

The current ELSA operator interface is based on a menu driven graphics package running on two consoles equipped with high resolution color monitors. Beside standard keyboards, trackballs and push-buttons are used as the main input devices. The interface allows full interactive access to all machine parameters and can be easily adapted to the special requirements of the operator. A first version of a simple control language is already used to automate machine physics measurements.

The ELSA control system proved to be reliable and flexible during one year of operation. The adaption to changing accelerator hardware turned out to be rather simple. The system showed extremely few failures, those were mainly due to host computer shutdowns. It has reached a high degree of acceptance among experimentalists as well as machine physicists.

At present, major improvements and extensions are under development, aiming at an interactive and programmable operator interface which will combine machine steering, diagnostics and data analysis in one integrated environment. It will provide a high level programming language for accelerator physics and for control. For the experimentalists, the new system will offer an effective, easy to use tool.

Measurements with the Beam Position Monitors

The ELSA beam position monitor system consists of 25 capacitive pickups (same as used at DESY II) installed around the ring. Since ELSA works in a multi-bunch-mode with every bucket filled, the BPM has to be sensitive to the same frequency as the accelerating RF. The average signal strength of this component as measured with a spectrum analyser at the pickup buttons having a 50 Ω termination is 1.1 mV per mA beam current. Horizontal and vertical difference signals and the sum signal are generated out of the four button signals with RF hybrid junctions. One of the difference signals can be selected with a GaAs RF switch, then it is amplified and sent to the homodyne 500 MHz receiver[2]as well as the amplified sum signal. To calibrate the whole circuit it is possible to switch a constant RF signal to both channels, enabling the correction of phase differences or unequal amplification of the two channels.

The dynamic range of the receiver amounts to 30 dB, but can be shifted with switchable amplifiers in a range of 50 dB to fit the actual intensity. The bandwidth of the receiver is 20 MHz, so it is fast enough to perceive a single shot from the synchrotron (232 nsec) or to resolve the intensity distribution around the ring.

In the present state these signals are sampled by a digital oscilloscope at a rate of 100 MHz. Six prototypes of the described RF-electronics are in operation already. In the near future, however, a readout system for each BPM (sampling rate: 10 MHz to 78 kHz, buffer depth: 8192 values) and the final electronics for each BPM (resolution: 0.2 mm) will be installed. This system will make it possible to record the beam position at each monitor covering a period of 0.8 to 105 msec.

The position monitor system was designed as a multi purpose beam diagnose system. All measurements described in this paper have been carried out using the 6 already operating prototypes, except for intercepting screen monitors used in the transfer beamline and a dc-current-transformer[3], used as intensity monitor in ELSA. During the setup of the injection the first monitor in ELSA was used as a fast relative intensity monitor to see the temporal distribution of the injected beam's intensity. The number of turns seen by the monitor has often enabled us to draw conclusions concerning faulty devices.

By spectral analysis of a betatron oscillation excited with a fast kicker magnet and sampled at one BPM we determined a variety of parameters - the horizontal and vertical betatron tune and the synchrotron tune; by varying the accelerating RF frequency and amplitude and measuring the betatron and synchrotron tune we calculated the chromaticity and the RF over-voltage factor.

In the storage mode horizontal coherent betatron oscillations were excited by firing one kicker. The damping of these oscillations ("Landau damping") was studied under different conditions (different betatron tune, sextupole strengths and different intensities). With the help of a tracking program we were able to simulate this Landau damping process and to estimate the integral octupole strength in the ring (approx. 30 $\frac{1}{m^3}$). However, the observed damping time depends on the circulating current and is shorter at higher intensities.

An orbit correction program doing least square or harmonics correction is operating already. All 24 main dipoles are equipped with backleg windings as horizontal correctors and additional small magnets are used as vertical correctors. To check the function of the orbit correction system we measured the horizontal closed orbit with the 6 existing prototypes ($X_{rms} = 3.4$ mm) and corrected it successfully at this monitors using 9 corrector magnets ($X_{rms} = 1.25$ mm). Note that complete orbit correction requires all monitors, the described measurement could only test the orbit correction system installed so far.

Furthermore we set up a test to estimate the accuracy of the prototype monitor electronics: Varying the RF frequency forces the electrons to an dispersion orbit. The standard deviation of the measured positions from the one, which was calculated using the dispersion function, then yields an estimate of the accuracy. Although there are problems in the calibration unit of the prototypes the accuracy as measured by the described procedure is better than 0.2mm.

Extraction from ELSA

The electron beam is extracted from ELSA via a slow resonant ejection near a third integer resonance, driven by four extraction sextupoles in the dispersion free sections. Four ironless quadrupoles shift the machine tune continuously from the injection value to $4\frac{2}{3}$, the maximum tune shift possible at 1 GeV is $\Delta Q = 0.032$.

Problems arised from the 600 Hz ripple on all the magnet power supplies due to a 12-pulse rectifying system. Recently the ripple on the quadrupoles has been compensated by active and passive filters. In subsequent runs the machine's behaviour near resonance has resembled much more the theoretical calculations than before. Especially the influences of the three different sextupole families on the resonance strength were as expected. Likewise the time structure of the external beam can easily be modified by changing the shape of the control curve for the current of the ironless quadrupoles. An active filter for the dipole power supply is under construction but first tests have shown that a passive filter is necessary too.

In the stretcher mode the extraction time normally is 20 msec. Then up to 40 nA are delivered to the electron beam experiment. Lower intensities are necessary for the tagged photon facilities and can be obtained, e.g. by expanding the extraction times. Extraction times up to 200 msec (Figure 2) were tested, the large scale time structure exhibits a smooth behaviour and there are no gaps in the spill-out.

The effective duty factor was measured by one of the experimental groups by counting the random coincidences between two counters of their tagging system and using the formula:

$$d_{eff} = \frac{\dot{N}_1 \cdot \dot{N}_2}{\dot{N}_r} \cdot \tau \, ;$$

$\dot{N}_1$ and $\dot{N}_2$ are the individual counting rates, $\dot{N}_r$ is the random counting rate, measured as coincidence between N_1 and N_2 with coincidence resolving time τ. The used counters have pulse lengths of 10 nsec which leads to a coincidence time of 20 nsec, which is short compared to the revolution time of ELSA (548 nsec). Thus this method is sensitive to unsymmetries in the filling of the stretcher. After installation of the filters for the quadrupole power supplies, the achieved values of the duty factor are 35 %.

Conclusions

The ELSA control system offers an effective tool to control all necessary machine parameters; thus it has proved to be an essential part of the stretcher.

In the storage mode ELSA turned out to be an excellent source for synchrotron radiation which will be used in the near future.

The duty factor of ELSA has been enhanced remarkably and in addition with the so far measured spill-out intensities good beam conditiones for the three experimental facilities could be achieved.

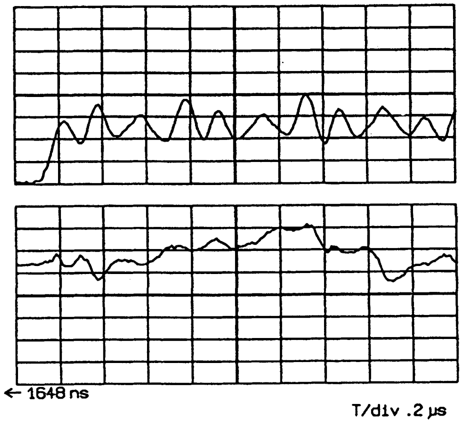

FIGURE 1
Two BPM signals of the first three revolutions after injection into ELSA are shown. The shaving extraction method used for the extraction from the synchrotron leads to a complete filling of ELSA with a small variation in intensity over the revolution time of 548 nsec (above). Below the relative beam position in the horizontal plane is shown. The intensity signal depends slightly on the beam position what causes the variation in the shape of the intensity signal from one revolution to the next. The vertical axes have linear units.

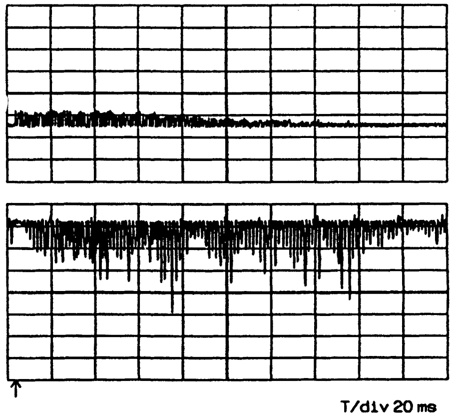

FIGURE 2
In the upper picture the intensity signal from a BPM in ELSA is seen over a time of 200 msec. The lower picture shows the signal of a photomultiplier in the extracted beam. The vertical axes have relative units.

References

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[3] K. Unser A Toroidal D.C. Beam Current Transformer with High Resolution (CERN-ISR-OP/81-14)