First Results of Beam Storing in the ESRF Booster Synchrotron

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Abstract

The 6 GeV fast cycling booster synchrotron of the ESRF can be used as a storage ring at energies between 160 MeV and 1.5 GeV with ramping times around 3 sec.
Currents up to 7 mA in multibunch mode and 0.06 mA in single bunch mode can be accelerated and stored.
Measurements of beam stability, beam size and bunch length at different energies between 160 MeV and 1.5 GeV are presented. Turbulent bunch lengthening and intrabeam scattering can explain the measured beam size and length.
The RF system designed for operation up to 6 GeV allows the application of large over voltages. The possibilities of obtaining short bunches are explored. The bunch length measurement in the turbulent regime depending on the energy and accelerating voltage has been used to probe the impedance of the machine for nearly constant small beam current of 0.05 mA. A second injection kicker is installed and first accumulation has been achieved.

1 INTRODUCTION

Synchrotron light source injectors usually have to operate only a small fraction of the operation time of the light source. This brings up the idea of using the injector for purposes other than injection. The ESRF full energy injector is a fast cycling booster synchrotron with an emittance of $1.2 \cdot 10^{-7}$ m rad at 6 GeV. It can be operated at 1.5 GeV as a storage ring with emittances of 8 nm rad which is similar to other third generation VUV and soft X-ray light sources. Two meter long, zero dispersion straight sections could allow the installation of insertion devices or other test equipment. This encouraged the idea of exploring possibilities of using the ESRF injector as a synchrotron light source and test facility.

2 EXPERIMENTAL SETUP

Visible light emitted from one dipole was used to measure the beam size and the bunch length. The beam size is obtained by forming an image of the beam cross section. The longitudinal bunch shape and length is probed by measuring the time structure of the radiation with a Hamamatsu dual sweep streak camera (C-5680-31). Figure (1) gives an overview of the set-up.

To ramp the energy the dc-power supplies of the white circuits are driven and controlled independently. A constant accelerating voltage is used during the ramping. Chromaticity compensation during ramping is essential to reach large single bunch currents. Closed orbit correction, especially at low energies, during ramping is important for accumulation tests. The dc-steerers of the ESRF booster synchrotron allow only closed orbit correction for one energy during ramping.

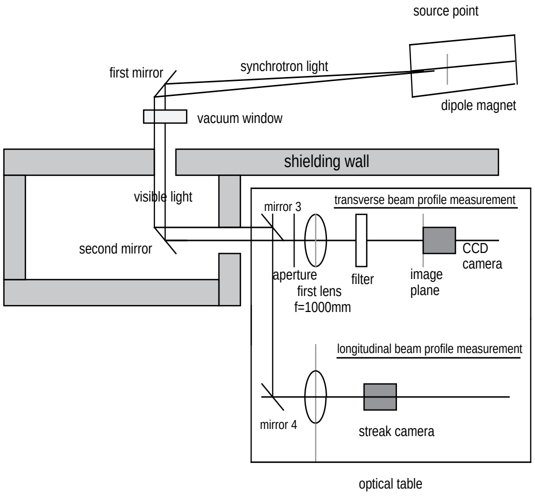

Figure 1: Schematic illustration of the synchrotron light diagnostics.

3 BUNCH LENGTH MEASUREMENTS

The bunch length measurements were done with a nearly constant current in single bunch mode to avoid multi bunch coupling. The maximum storable current was limited by the injection and ramping to 0.06 mA. The minimum current delivering enough light for bunch length measurements with the streak camera was 0.03 mA ($2 \cdot 10^8$ particles per bunch). The shortest bunches are obtained in single bunch mode and are of the order of (13 ± 2) ps at 1 GeV for a stored current of (0.04 ± 0.01) mA (≈ 2 A peak current). Synchrotron oscillations (up to several sigma) were visible at all energies.
Figure (2) shows the simulation and measurement of a bunch length for an energy of 1.2 GeV. For each accelerating voltage the measured bunch length follows the curve giving a larger bunch length as predicted by the Boussard Criterion (equation (1)).

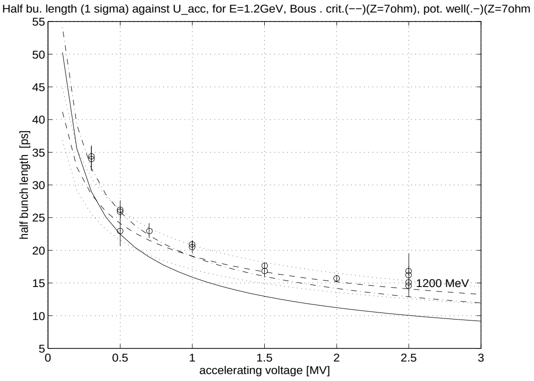

Figure 2: Bunch length versus accelerating voltage at E=1.2 GeV. The circles are the measured values with their statistical error. The solid line is the natural bunch length. The dashed line is obtained with the Boussard Criterion using the average impedance including the error (dotted lines). The dash-dot line is obtained from a pure inductive impedance model which is used in the potential well region. The calculations were done for a current of 0.035 mA.

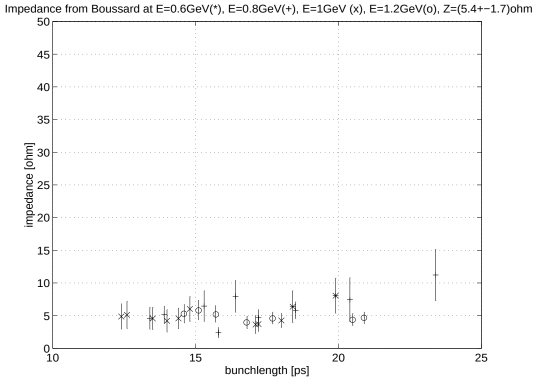

Figure 3: Calculated impedances with the Boussard Criterion. The error is mainly due to the accuracy of the current measurement.

4 THE BROAD BAND IMPEDANCE

In the turbulent regime the Boussard Criterion predicts that the bunch length is a function of the accelerating voltage (U_{acc}) and is independent to the beam energy.

$$\frac{\sqrt{2\pi}\cdot I\left(|\frac{Z_{\parallel}}{n}|\right)}{\omega_{rev}^3\sigma_T^3\cdot q\cdot U_{acc}\cdot\cos\Phi_s}\leq 0.88 \tag{1}$$

ω_{rev} is the revolution frequency, q=harmonic number, Φ_s=synchrotron phase, I is the average beam current, σ_T is the bunch length

To probe the broad band impedance of the machine the bunch length was measured in single bunch mode in dependence on the beam storing energy and the accelerating voltage for nearly constant beam current of 0.05 mA.

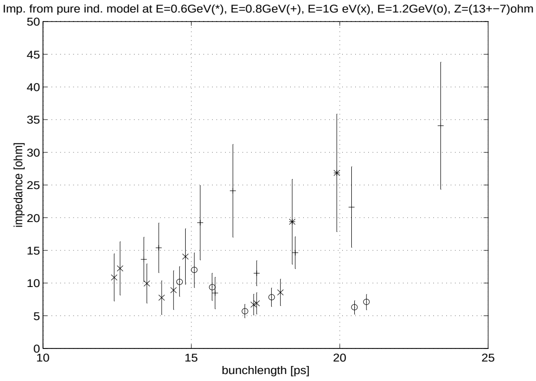

Figure 4: Calculated impedances with the pure inductive model. The error is mainly due to the accuracy of the current measurement.

The impedance obtained with the Boussard Criterion from all measurements which show significant bunch lengthening is nearly constant and the variation is small (figure (3)). The broad band model allows to explain the measured bunch length with an impedance of:

$$\left(\frac{Z_{\parallel n}}{n}\right)_{Boussard}=(5.4\pm 1.7)\Omega \tag{2}$$

Measurements on third generation machines have shown that the impedance of these machines shows a more or less inductive behaviour (no energy widening occurs) [3]. A numerical solution of the Haissinski equation for the pure inductive case can be used as a model for a pure inductive machine or in the potential well regime of a broad band impedance [2] [4]. The pure inductive model predicts an energy dependence of the bunch length for low currents [2]. If the bunch length is energy independent, a fit with the pure impedance model would lead to an impedance which depends on the energy. The impedance calculated with the pure inductive model shows a large variation and an energy dependence (figure (4)). Using an average impedance the measured bunch length is not described as good, as is the case with the Boussard Criterion, due to the energy dependence of the bunch length. In the potential well regime, below the current threshold for turbulent lengthening the pure inductive model can describe the bunch lengthening with the impedance obtained from the Boussard Criterion. The ultimative single bunch current limitation given by the transverse mode coupling instability has been estimated to be between 10^9 and 10^{10} particles per bunch with the code ZAP [1] and the measured longitudinal impedance.

5 LIMITATION DUE TO THE VACUUM SYSTEM

Measurements of the vacuum dependence on the beam current and beam energy have shown that the desorption from the vacuum chamber decreases the beam lifetime due to

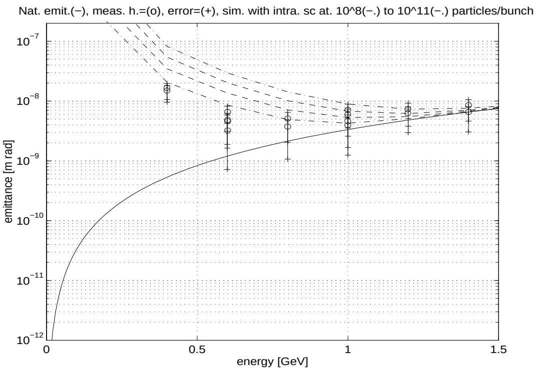

Figure 5: Measured emittances with $2 \cdot 10^8$ particles per bunch (coupling less than 0.3) in 4 bunch mode (o). The error is given by the (+).

The natural emittance depending on the energy is given by the solid line. Intrabeam scattering calculation results for a coupling of 0.2 with considered turbulent bunch lengthening are indicated with: $2 \cdot 10^8$ (dash-dot line, lowest curve) then in an upwards direction with $2 \cdot 10^9$ (–), $2 \cdot 10^{10}$ (–) and $2 \cdot 10^{11}$ (dash-dot line) particles per bunch.

gas scattering effects (e folding lifetime=1hrs expected for 10 mA at 1.5 GeV). In addition, the pressure increase in the cavities limits the safe operation of the RF so that from tests with beam storage in the cycling mode [2], a limitation of the storable beam current in multibunch mode around 10 mA at 1.5 GeV can be expected. For lower energies the desorption is smaller but all problems with multi particle effects will be increased. The Touschek effect is not limiting lifetime, in case of the booster synchrotron, for energies between 0.4 and 1.5 GeV.

6 EMITTANCE MEASUREMENT

From intrabeam scattering simulations with the code ZAP [1] the smallest emittances for large currents (10^{10} particles per bunch) can be expected at energies between 1 and 1.2 GeV (see figure (5)). The results of emittance measurements with $2 \cdot 10^8$ particles per bunch in single bunch mode at different energies are shown in figure (5). It was observed that in multibunch mode, due to multibunch coupling the emittance is larger than the natural emittance and that the natural emittance can only be measured below ≈ 0.2 mA stored beam current. The measured horizontal emittances for low currents in multibunch mode at 600 and 800 MeV are close to the resolution of the synchrotron light monitor. The vertical emittance is below the resolution limit of the light monitor so that only an upper estimation of the emittance and the coupling can be given ($\epsilon_z < 1 \cdot 10^{-9}$, coupling$< 0.25$). The emittances measured are in the range of the measurement error in accordance with the intrabeam scattering simulations.

7 ACCUMULATION

A second recently installed injection kicker allows beam accumulation in multi bunch mode. After each injection the beam is ramped to a higher energy to obtain additional damping. Accumulation has been proven. The equilibrium current reached between injected current and current lost on the septum is smaller than the current which can be injected with an on-axis injection. Further tests to improve the kicker bump and the injection path are planned.

8 CONCLUSION

The possibilities for storage of beam in a booster synchrotron with small emittances in principle has been shown. The emittance enlargement due to intrabeam scattering for larger currents is acceptable. The large impedance of the machine limits the obtainable peak currents and bunch length in single bunch mode. As it stands at present, for energies above 1.2 GeV the vacuum system limits the lifetime and storable current in multi bunch mode. Low energy accumulation is possible but further investigations are needed to explore the maximum current achievable.

In its present state the ESRF booster synchrotron can be used as a test facility for accelerator components and can be used to study beam dynamic effects.

9 REFERENCES

[1] M. S. Zisman et al.; ZAP user's manual; December 1986

[2] G. Schmidt; Beam Dynamic Studies in Cycling and Storage mode on the ESRF fast Cycling Booster Synchrotron; to be published

[3] P.Brunell, G. Flynn, M. P. Level, A. Nadji, M. Sommer, H. Zyngier; Experiments with low and negative momentum compaction factor at Super-Aco, 10th ICFA Beam Dynamics Workshop; Grenoble; January 96

[4] G. Besnier, JL Laclare, C. Limborg; Difficulty in obtaining short intense electron bunches in conventional storage rings, 10th ICFA Beam Dynamics Workshop; Grenoble; January 96

The ESRF Booster Synchrotron in Numbers	
Machine Lattice	FODO
Circumference	299.622 m
Number of cells	39
Bending Radius	22 m
DC-Storing Energy	between 160 MeV and 1.5 GeV
Standard Working point Q_x/Q_z	11.8/9.8