

## PROPOSAL FOR A FREQUENT INJECTION MODE AT DELTA

G. Schmidt; M. Benna; U. Berges; J. Friedl; A. Gasper; M. Grewe; P. Hartmann; R. Heine; H. Huck; D. Schirmer; S. Strecker; T. Weis; K. Wille; N. Zebralla

DELTA, University of Dortmund, Germany

### Abstract

The Dortmund Electron Accelerator (DELTA) changed its scope during the last years from a test accelerator mainly dedicated to the development in the field of accelerator physics (including FEL) into a local 1.5 GeV synchrotron light source. DELTA is now operated for 3000 h per year including 2000 h beam time for synchrotron radiation use. The maximum beam current is limited by rf power. A 60 kW klystron is operated with one cavity. To increase the average beam current two possibilities can be discussed. The peak current can be increased by the installation of additional rf-power. Another possibility is to use a frequent injection (FI) scheme where the peak current is not enlarged but the number of injections is increased to establish a quasi constant beam current.

This article discusses the possibility to install a frequent injection mode at Delta and shows results of first tests.

### INTRODUCTION

The storage ring facility DELTA is operated by the Institute for Accelerator Physics and Synchrotron Radiation at the department of Physics (University of Dortmund). The facility consists of a 75 MeV S-Band LINAC, a ramped full energy injector storage ring BoDo and the 1.5 GeV main storage ring Delta (Fig.1).

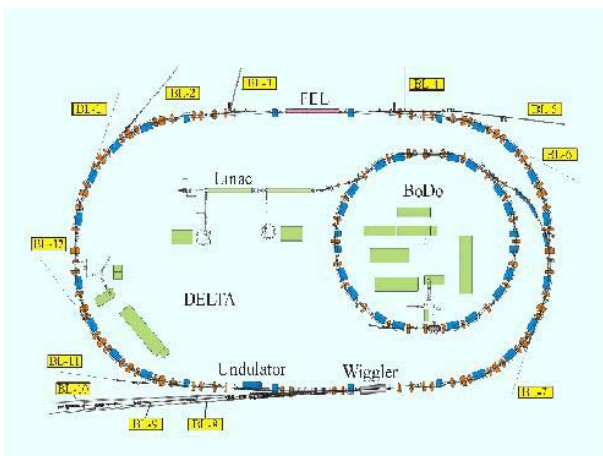


Figure 1: The DELTA accelerator complex

### FREQUENT INJECTION (FI)

A decent user week allows to integrate a beam current of around 8.5 A hrs (see figure 2).

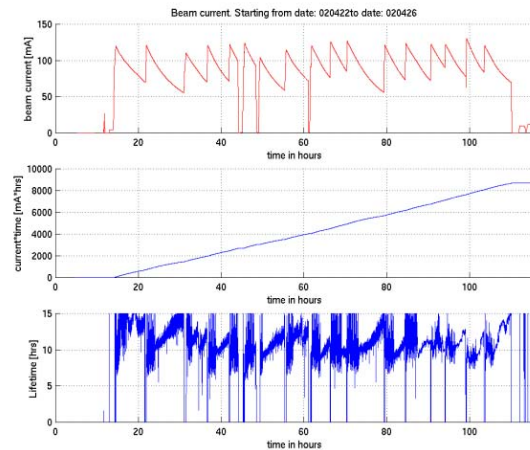


Figure 2: Beam current, integrated beam current and lifetime versus time during a decent week for user operation in 2002.

For a quasi constant maximum beam current around 120 mA during frequent injection and a machine operation of 100 hrs/week Delta could deliver 12 Ahrs/week. This is an increase of more than 30 % compared to the standard operation without an increase of the maximum beam current i.e. maximum heat load on the vacuum chamber. A main advantage for the beamline user is the constant heat load on their experiment if Delta is operated with constant beam current and beam shutters opened during injection. For the operation of the storage ring the constant heat load on the vacuum chamber directly reduces the magnet and chamber movements and increases the machine stability [1] i.e. reduced closed orbit drift. The mode of operation which we named 'frequent injection' must fulfil the following two requirements:

- beam shutters may stay open during injection.
- the beam current is kept within a given variation range.

At Delta the frequent injection mode is planned with a current variation of around  $\pm 5$  mA (see chapter 3). Together with a beam lifetime of better than 4 hours this allows to inject every  $\sim 30$  min and to switch off the injector chain in between. A trigger for the beamlines will allow to stop data acquisition during injection (for some damping times after the pulsed injection elements have been triggered ( $\sim 100$  ms)).

The technical feasibility of such an operation mode has been demonstrated with beam shutters closed (see figure 3).

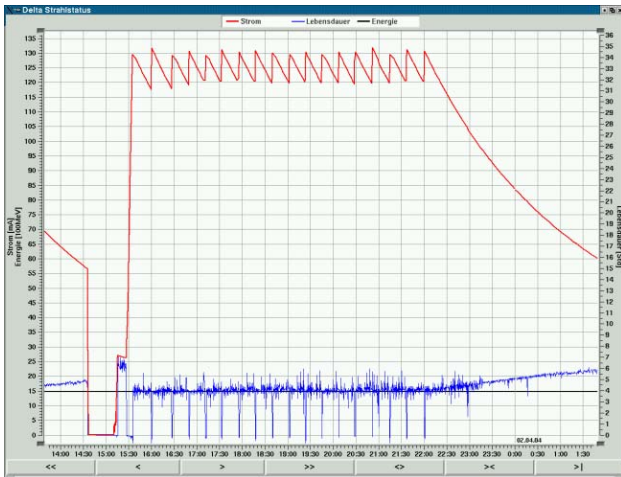


Figure 3: Demonstration of FI Mode at Delta. Red (upper curve): Beam current, blue (lower curve): Lifetime versus time. Frequent injection has been demonstrated during 7 hours with  $\pm 5\%$  beam current stability while beam shutters were closed.

*Advantages of Frequent Injection at Delta*

- Quasi-constant heat load on the vacuum chamber of the storage ring. Reduced magnet and orbit drift due to the reduced changes of the heat load on the vacuum chambers by synchrotron radiation.
- Simplified handling of the storage ring due to enhanced thermal stability due to reduced beam current variation.
- Increased average beam current without increase of maximum heat load on vacuum chambers.
- No additional rf-power needed.
- No dedicated beam time needed for injection, where shutters have to be closed. At standard operation (in the year 2003)  $\sim 6$  hrs per week were required for injection (corresponds to  $\sim 6\%$  of beam time for user operation).
- Experience has shown that the more stable machine operation in FI-Mode will reduce the losses during injection and reduces the radiation level inside the DELTA hall during injection (see figure 4).
- Lifetime limitations at lower beam energies or at larger beam currents like the Touschek-effect, become less important for storage ring operation, due to the quasi constant beam current. This is interesting for machine studies and Free Electron Laser (FEL) operation at lower beam energies [10].

*Disadvantages of FI at Delta*

- The injector chain is used more often.
- A cross-talk between transfer-channel, booster synchrotron and Delta storage ring reduces the orbit stability. The orbit inside the storage ring is influenced by ramping magnets of the booster

synchrotron (BoDo) and pulsed components. A fast orbit feedback (or feedforward) is needed or a trigger for the user experiments to allow them to stop data acquisition during the time of the injection process when their measurement might be disturbed.

- The accelerator system becomes more complex and needs higher stability and reliability e.g. additional fast orbit feedback systems, high reliability of injector.
- Additional equipment to satisfy radiation safety aspects (measurement and/or shielding around some beamlines) might be necessary.
- Permanent magnet undulators may suffer from radiation damage if the gap stays closed during injection. At Delta only one undulator (U55) uses permanent magnets. Studies to investigate the beam loss during injection in the U55 vacuum chamber and how the dependence of the radiation dose onto the magnet structure depends on the undulator gap are under investigation. First measurements with weekly changed thermo luminescence dosimeters have shown that the expected lifetime of the undulator magnets with closed undulator gap should be around 50 years before magnet field degradation can be measured [3]. To allow online monitoring of the radiation dose on the undulator a system based on optical fibres, which change their transmission with radiation exposure, will be set up during a diploma thesis [4]. The feasibility of such a dose monitoring system at Delta has been shown [8].

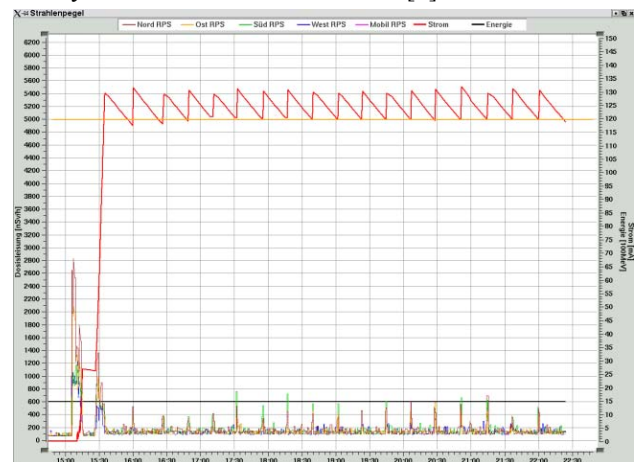


Figure 4: Radiation level on 4 radiation monitors inside the Delta hall (4 lower curves) during a FI test run with shutters closed. Time [hrs] is shown on the x-axis. Injection was switched on every  $\sim 25$  min (peaks on radiation level). Beam current: upper (red) curve. During most of the injections the peak level stays below 600 nSv/hour. Even with a permanent running of 2000 hours in this mode we would stay far below 1 mSv/ year limit. The dose rate during the injection from 0 mA to 125 mA is much higher than during FI. This can be explained with the increased thermal stability of the storage ring.

## TECHNICAL REALISATION OF FREQUENT INJECTION AT DELTA

The allowed current variation of  $\sim \pm 5$  mA is a good compromise between current stability and number of injections. Less than 10 BoDo ramp cycles are needed to refill the 10 mA beam current (see figure 3 and figure 4). The refill is then possible in about 1 min. Using frequent injection will not increase the energy consumption of DELTA compared to the present way to operate the accelerator complex.

The following list describes the important improvements to be made for the Delta accelerator complex to establish FI.

### *Improvement on the Injection Chain*

To allow injection with good reproducibility the following improvements have to be achieved:

- stable operation of linac, BoDo, transfer channels, pulsed elements in BoDo, transfer channel and Delta.
- Good transfer efficiency at 1.5 GeV to reduce radiation level inside the experimental hall. BoDo extraction, transfer channel and injection to Delta have to be optimized.

The low radiation level inside the experimental hall during operation with FI (figure 4) shows that such an operation is possible without reaching the dose rate limit of 1 mSv/year inside the experimental hall.

### *Orbit Stability during Injection*

To obtain a good orbit stability the cross talk of BoDo magnets with Delta must be minimized. Magnetic shielding and a slow feedback or feedforward system around the Delta injection area should allow to minimize this effect onto the Delta orbit [9]. A measurement program to understand the crosstalk has been started. If necessary a global orbit feedback has to be installed to minimize the effect on the Delta storage ring orbit.

The transfer channel dipoles are pulsed with 2 ms pulse length. A feedforward, feedback system or magnetic shielding has to be discussed for compensation.

The pulsed magnets like septum and kicker have an influence on the beam orbit, too [7]. A very fast feedforward is needed to close the kicker bump with high accuracy during the complete bunch train.

A trigger for the beamline is in preparation to allow the beamline user to stop their measurements for some time during injection to get rid of beam oscillations generated by the pulsed injection elements.

In addition a software counter can be installed which shows the beamline user the time to the next injection to allow them to synchronise their experiment [6].

Experience during user operation will show if such systems are necessary.

### *Radiation Protection*

Together with the controlling authorities necessities will be worked out to fulfil the high personal radiation protection requirements at Delta.

Backtracking of particles for several beamlines has shown that particles can not enter the beamlines if beam is stored in Delta [5]. An interlock system will be built to allow FI only with some already stored beam in the Delta storage ring. A similar system runs at the ESRF during the injection mode with front end open[6].

### *The Way to FI at DELTA*

Most of the developments have been done and tested with beam shutters closed.

In the second test phase one beamline will serve as a test for measurements concerning radiation safety aspects together with the controlling authorities. Results are expected during the next year.

Frequent injection with shutters open should become a special operation mode implemented beamline after beamline.

The standard mode of operation (beam shutters closed during injection) will always be possible on user request.

## SUMMARY

Frequent injection with open shutters at DELTA is a very promising possibility to increase the average beam current. A most important benefit due to frequent injection is the stabilisation of the heat load on the storage ring vacuum chamber and the user experiments. This increases both the thermal stability of the Delta storage ring, as already demonstrated during tests as well as the stability of the user experiments.

The development of a frequent injection system can be done without major interference with the operation of DELTA as a synchrotron radiation source.

Financial resources must be invested into the development of diagnostics, feedback systems, as well as the control system, and radiation safety aspects must be satisfied.

## REFERENCES

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