DIAGNOSTICS AT CRYRING

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Abstract

CRYRING, the storage ring for ions at the Manne Siegbahn Laboratory has been used for experiments with atomic and molecular ions since 1993. The beam diagnostics that is in used now, in 2009, towards the end of the lifetime of this ring, at least in Stockholm, is the result of developments during its around 20 years of use. These will be presented in this article, together with some experiences regarding the use of the diagnostic equipment that has been gained during this time.

OVERVIEW

CRYRING is a 52 meter accelerator/storage ring at the Manne Siegbahn Laboratory at the Stockholm University. Since 1993 it has been used to study a vast selection of atomic and molecular ions. Several different types of ion sources have been used to supply the desired ions to the experiments, such as an EBIS, an ECR and different discharge sources, mainly for the production of singly charged ions. Also a caesium-sputter ion source has been used to produce negative ions. The long list of ions that have been stored in the ring includes singly and multiply charged ions of masses from 1-208 amu, from protons to $^{208}Pb^{55+}$, at energies from 38 eV/u – 92 MeV/u. The full list of ions can be found at [1]. For many of these ions the intensities available from the ion sources have been very small, in some cases even below 1 nA. These low intensities have been a challenge for the diagnostics and have prompted necessary improvements of the sensitivity of the equipment which will be described in more detail in connection with the discussion of the different parts of the diagnostics below. A more comprehensive description of CRYRING can be found in [2,3].

The diagnostic equipment available in CRYING consists mainly of the following parts:

Beamlines:

- Fluorescent screens
- Faraday cups
- Strip detectors

Storage ring:

- Faraday cups (one combined with a fluorescent screen)
- Electrostatic pickups
- Schottky detector
- DCCT (Bergoz)
- ACCT (ICT, Bergoz)
- Residual gas ionization beam profile monitor
- Neutral particle detectors

Most of the instruments in this list can be found also in most other storage rings, but I hope that a description of the different parts, together with some comments regarding our experiences and developments during the years, could be valuable for other users of similar equipment.

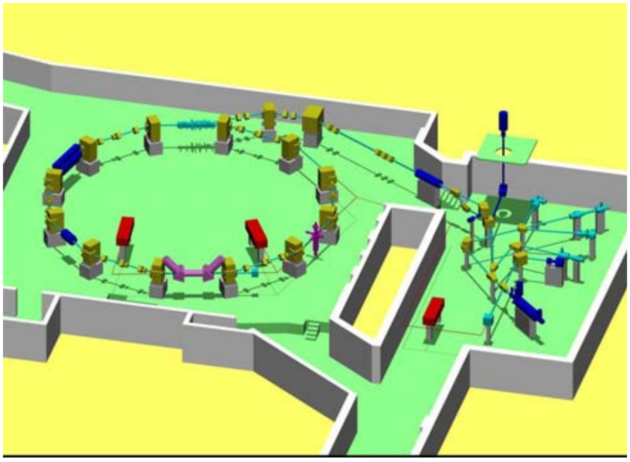

Figure 1: The CRYRING facility

BEAMLINE DIAGNOSTICS

The fluorescent screens used in the beamlines are of two kinds. Closest to the ion source a CsI(Tl) is used due to its high sensitivity, also for low energy ions. The other screens used are of the type called Chromox, from Morgan Technical Ceramics, made of aluminium oxide doped with chromium oxide. The main reasons for the use of Chromox screens in the beamline are their robustness and UHV compatibility. The outgassing properties of CsI(Tl) is not well known, but we suspect that it could be too high for a UHV environment, furthermore, they might not withstand the required baking temperature to 300°C. We do not exclude, however, that this material could also be used in a UHV environment, but in such a case, their properties would need to be tested. All the screens are covered with a thin metal mesh (95% transparency) to avoid charging up of the surface. The beam pulses after the RFQ is of the order of 1 ms long and intensities down to a few tens of nA can normally be seen on the Chromox screens when using standard video cameras. For ions with Q/A<1/4, which are not accelerated in the RFQ and for which the RF amplitude used is much lower, we have used the possibility to increase the pulse length to be able to see weaker beams without exceeding the maximum average power that can be cooled away from the RFQ structure. since the light emitted from these screens is dark red, it is a good idea to increase the sensitivity of the camera by removing the IR filter that normally is mounted in front of the detector of standard video cameras. Some darkening of the screens with exposure and a consequent loss of sensitivity has been observed, but not to an extent that frequent replacement of the screens has been necessary. The most important use of the screens has been to centre the beams in the quadrupoles by varying the magnetic fields and adjusting correction elements so the centre of the beam spot stays in the same place.

As an alternative to fluorescent screens, strip detectors are also used. They have the evident drawback that one only gets two one-dimensional profiles instead of a true two-dimensional picture. An advantage is that there is no need for an extra port with a window for a camera. Partly for historical reasons, there is only one strip detector in the beamline from the main ion source. However, in the beamlines from the EBIS as well as the one from the ECR source, they have been extensively used.

Faraday cups are used to measure the exact ion currents along the beamlines, and also in two positions in the ring, first inside the injection tank and then after almost one complete turn in the ring. After optimization of the current in the second cup, normally the beam is circulating when the cup is retracted.

RING DIAGNOSTICS

Electrostatic Pickups

As mentioned above, there are two Faraday cups in the ring. The rest of the diagnostics are non-destructive. There are nine pairs of electrostatic pickups. Initially, during the commissioning of the ring, these were essential for measuring and finding the corrections of the closed orbit of the beam, but once the basic settings of all the elements were found, we have mostly relied on scaling these parameters to find initial values that are good enough to store the beams. To improve the possibility to work with weak beams, four of the original preamplifiers have been replaced by state of the art low-noise amplifiers. These are home built and have input circuits with two FETs, type 2SK300, connected in parallel. The equivalent input noise is 5 μVrms @ 10 MHz BW. The gain is 52 dB.

One of these pickups is used for optimization of the machine settings by maximizing the signal as measured by a spectrum analyzer set on zero span on the revolution frequency in the ring or a harmonic thereof. Since the optimization procedure often consists of making small changes of the settings of the elements while looking for improvements, a monotonous and tiring procedure for the operator, a LabVIEW program that performs these actions is instead used for the fine-tuning of the parameters. It systematically goes through a set of parameters which can be chosen by the operator and automatically stores any settings that give improved intensities. A screen shot of this program in action is shown in Fig. 2. Different input signals can be used, such as the pickup signal from the spectrum analyzer and the signals from the different

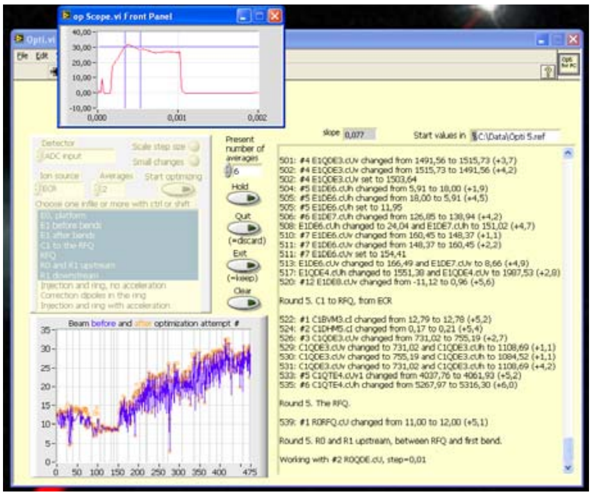

Figure 2: Screenshot from the automatic optimization program showing the result of several cycles of optimization.

Faraday cups. The history of the improvements can be found in the graph in the lower left corner of the screen.

Schottky Detector

The Schottky detector has mainly been useful for multiply charged heavy ions, since the signal is proportional to the ion charge squared. It is equipped with commercial low-noise amplifiers from Trontech. The most common uses of the detector are to monitor the intensity of the stored beam and to adjust the electron cooling. A particular use was the observation of ordering in the stored beam, which can be seen in Fig. 3, where the transition to a very narrow Schottky peak can be seen after 1000 seconds. [5]

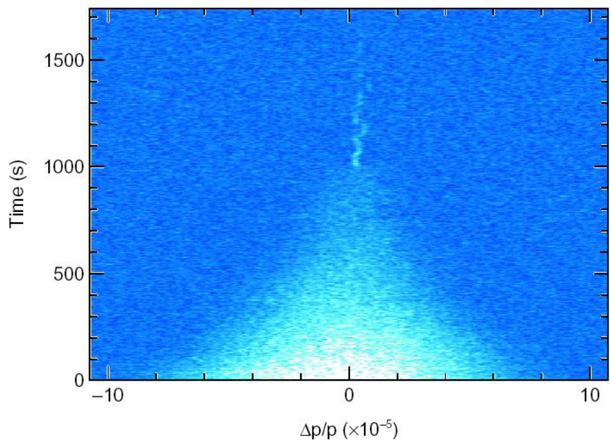

Figure 3: A sequence of Schottky spectra from a beam of Xe^{36+} ions showing the transition of the beam to an ordered state at around 1000 seconds.

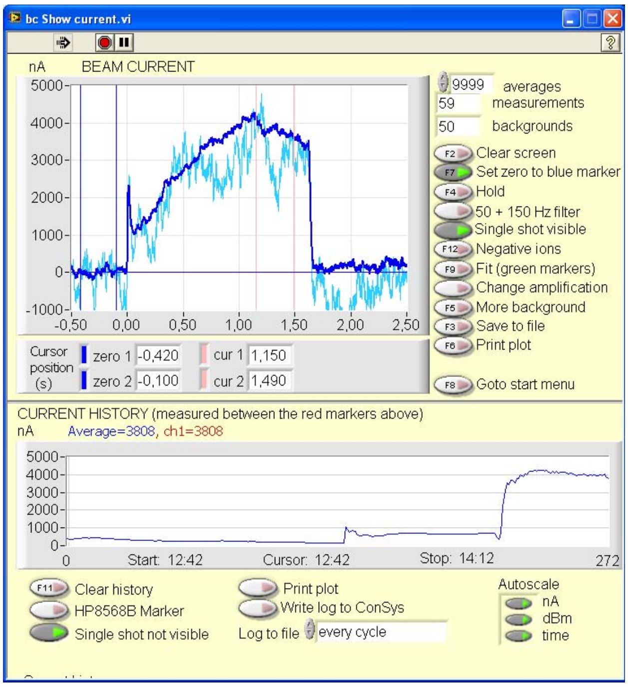

Figure 4: Screenshot from the LabVIEW program that is used for beam current measurements. This example shows injection, acceleration (1 s) and a short storage (0.5 s) of a beam of $^{19}F^{5+}$.

Current Measurements

Absolute measurements of the stored ion current in the ring are essential for many experiments. Two current transformers are used for this purpose, a DC Current transformer (DCCT) with which coating beams can be measured and an Integrating Current Transformer (ICT) which is used to measure pulsed beams. Both are manufactured by Bergoz Instrumentation. The DCCT has a noise level which is approximately 1 µA peak-peak while the noise of the ICT is more like a few nA. To improve the signal to noise levels, the signals from the transformers are in general averaged over several injections into the ring. Also, the background signal from the ramping of the magnets during acceleration normally needs to be subtracted. Another LabVIEW program is making this process easy. A screenshot from this program is shown in Fig 4. The original preamplifier of the ICT has been replaced by a home-built one with lower noise (1 nVrms/√Hz) and higher gain (80 dB). Also the integrator electronics has been replaced by a new version with gate widths with a ratio of 2:1, instead of the original 1:1 to make it easier to fit the signal from the bunch inside the measuring gate. Further details of the improvements made on the ICT can be found in [4], where also the use of the signal from an electrostatic pickup to extend the measurement range down to even lower beam currents is described.

Beam Profile Monitors

Two residual gas ionization beam profile monitors are installed, one for the vertical profile and one for the horizontal. These monitors detect ionized residual gas molecules that are created in collisions between the stored ions and the residual gas molecules. An electric field transports these ions towards a set of Micro Channel Plates (MCPs) from which a spatially resolved image of the area where collisions are taking place, i.e. of the beam trajectory, is obtained. The resolution is clearly less than 1 mm. This instrument is a very useful tool, in particular for optimizing the electron cooling. As can be seen in Fig. 5, it has also been used to measure the transverse cooling time [6].

Another MCP based detector, placed in the zero-degree exit of the straight section after the gas target, is used to register neutral particles. Since neutrals are created from collisions between stored singly charged ions and the residual gas molecules, this detector has been very useful to monitor the number of stored ions.

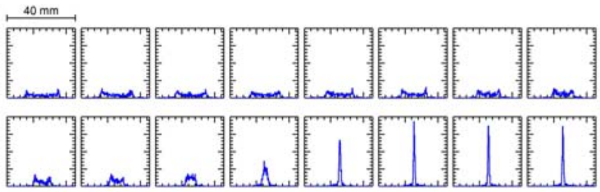

Figure 5: Vertical profiles of an F^{6+} beam during successive 61-ms intervals, starting 61 ms before the electron beam is realigned with the ion beam and cooling begins.

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