NONDESTRUCTIVE BEAM INSTRUMENTATION AND ELECTRON COOLING BEAM STUDIES AT COSY

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Abstract

To study the dynamics of electron cooling in a synchrotron only non-destructive instrumentation can be used. Beam diagnostics based on recombination is usually used to optimize electron cooling of protons (H^0-diagnostics). In the future HESR ring, however, this technique is not applicable due to antiprotons being accelerated. An Ionisation Profile Monitor delivers real-time data in both transverse planes allowing detailed analysis of beam profile evolution in COSY. Attempts to use scintillation of residual gas to measure beam profiles were very promising. So ionisation and possibly scintillation profile monitors become vital for optimization of electron cooling of antiprotons. The new beam instrumentation at COSY is introduced and its relevance for the new 2 MeV electron cooler project and the HESR is discussed. Results of electron cooling beam studies at COSY are presented.

INTRODUCTION

The main subject of this paper is the non-destructive beam profile monitors at COSY and their use during the electron cooling beam studies carried out in April 2010. Though the detailed analysis of the gathered experimental data is not yet complete, we would like to present some results, to illustrate the performance of the new beam instrumentation.

Commissioning of the Ionisation Profile Monitor (IPM) [1] opened new opportunities for electron cooling beam studies. High resolution real-time profile data was not available during previous electron cooling studies. The brief electron cooling run in April 2010 was solely devoted to electron cooling of protons at injection energy (45 MeV). The effect of the electron beam on proton beam lifetime and the mechanism of initial losses [2] in particular were the main subjects of the investigation.

BEAM INSTRUMENTATION

The IPM was designed at GSI keeping the requirements for the future FAIR machines in mind [3]. The ionisation products are guided to a position sensitive detector by transverse electric field. An arrangement consisting of an MCP stack (100x48 mm^2), a luminescent screen, and a 656×494 pixel CCD camera is used to detect ions in high resolution mode. The IPM actually contains two identical units to provide simultaneous measurements in both, horizontal and vertical, planes. The IPM is installed in COSY in the arc downstream of the cooler telescope. The data acquisition software was developed at FZJ with an emphasis on real-time display of beam profiles. The software also performs fitting and plots beam width and position vs. time. The beam current measured by the beam current transformer (BCT) is also displayed.

A Scintillation Profile Monitor (SPM) is being developed at COSY as a robust and inexpensive alternative to the IPM. The disadvantage of much lower event rate compared to the IPM and thus the necessity to locally add nitrogen to the residual gas is compensated by the much simpler mechanical design of the SPM. The light emitted by the gas in the vacuum chamber is focused by a lens onto a multichannel photomultiplier (PMT) array (Hamamatsu 7260-type, 32 channels, 0.8×7 mm photocathode, 1 mm pitch). The readout is performed using a multichannel current digitizer, developed at iThemba LABS [4].

EXPERIMENTAL RESULTS

Figure 1 shows the evolution of the horizontal and vertical proton beam profiles during electron cooling. Also shown is the beam width (sigma) as well as proton beam current. One can see that at this particular setting the cooling process takes 11 s after which the beam size does not shrink any more. Horizontal cooling appears to be much faster than vertical one. However, the width reduction is attributed to both processes - beam cooling and losses. Particles with large horizontal betatron amplitude are lost quickly. This process contributes to the fast reduction of horizontal beam width. It has to be noted that the transverse profile of the cooled beam exhibits characteristic tails corresponding to the particles whose amplitude is not cooled down even after an extended period of time. So the horizontal and vertical sigmas shown in the top graph actually represent (after a few seconds of cooling) the cooled core of the proton beam only. Protons are brought into COSY by means of multi-turn stripping injection. The electron beam was present all the time. The density of the cooled proton beam is typically above the instability threshold so the transverse dampers had to be turned on in order to suppress transverse coherent oscillations and beam losses [5].

Figure 2 shows the evolution of transverse profiles during cooling as well as the response to a sudden

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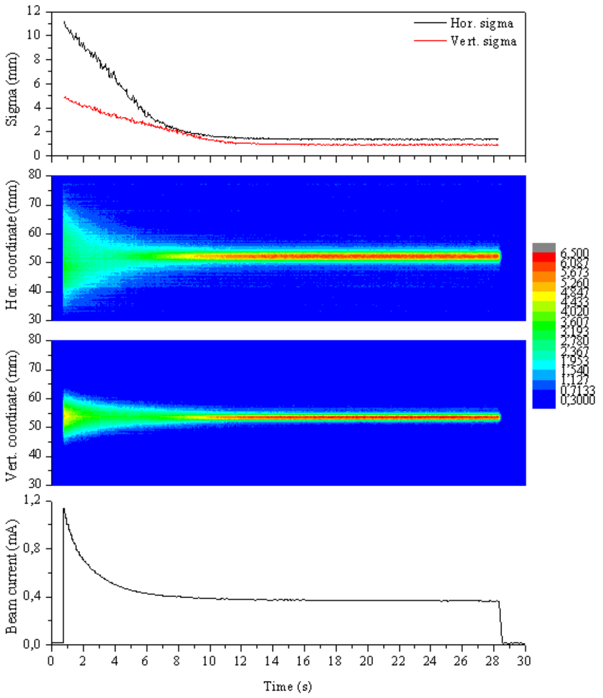

Figure 1: Evolution of transverse proton beam size (top plot) derived from Gaussian fits of the profiles measured by the IPM (both centre plots) during electron cooling. Beam current is reported by the BCT (bottom plot). Electron current - 163 mA, electron energy - 24570 eV.

change of electron energy from 24580 to 24480 eV. At about 23 s the electron energy was changed. This caused the profiles to become broader and afterwards the beam was cooled to a lower energy.

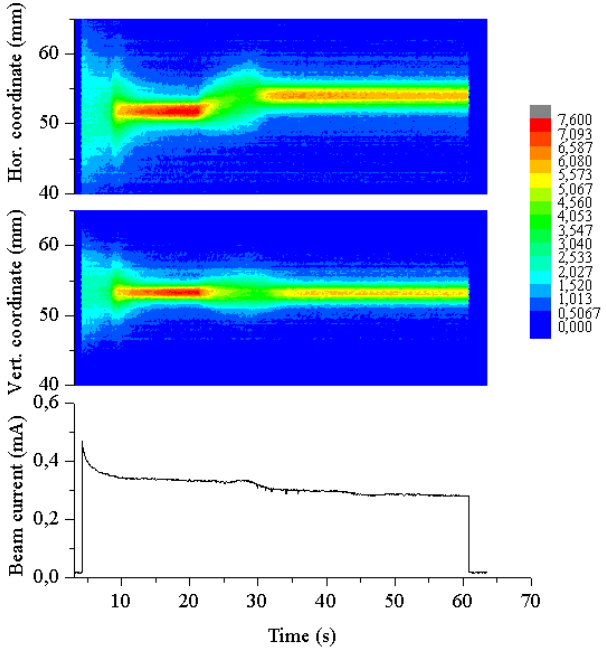

Figure 2: Evolution of transverse beam profiles. After about 23 s in the machine cycle the electron energy was reduced from 24580 to 24480 eV. Electron current - 180 mA.

Lower proton energy results in a shift of horizontal position due to dispersion at the IPM location, which was determined to be 2 m. In fact, the presence of dispersion at the IPM location may be very helpful for resolving small energy changes. This technique was used to estimate the mean value of the longitudinal friction force

$$F = \frac{2CE\Delta x}{l_c D\beta c\Delta t} \approx 1.9\cdot 10^{-4}\, eV/cm$$

where $E = 45\,MeV$ is the ion kinetic energy, $C = 184\,m$ the machine circumference, $l_e \approx 1.4\,m$ the effective length of the cooling section, $D = 2\,m$ dispersion at the IPM location, $\beta c = 8.97\cdot 10^7\,m/s$, $\Delta x \approx 2.25\,mm$ the horizontal displacement at the IPM and $\Delta t \approx 8\,s$ time required to reach the new energy. This value agrees well with previous measurements based on revolution frequency shift as a result of an electron energy step. However, the IPM appears to allow for greater accuracy compared to the frequency shift method. This can be explained by the fact that the horizontal beam profile has a well defined shape, which is not the case for the revolution frequency spectrum.

To find an optimum electron beam angle a scan was performed and the IPM profiles were recorded. Figure 3 shows the mean square deviation plotted vs. time for different electron beam angles. The black curve corresponding to the horizontal angle of -0.42 mrad and the vertical one of 0.56 mrad indicates the best cooling. In a similar way, electron beam position scans were performed as well. The injection duration was set to 2 ms to reduce horizontal beam size.

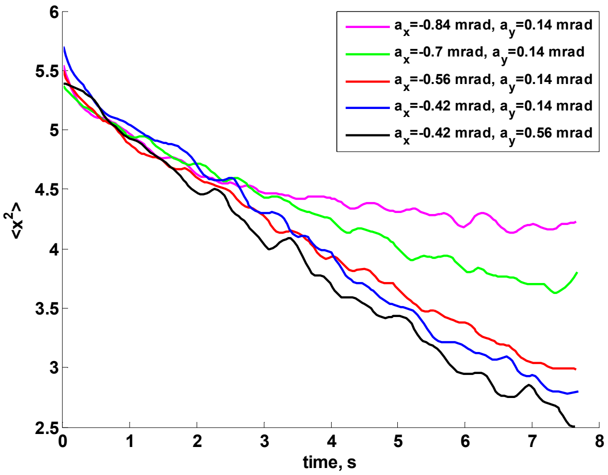

Figure 3: Mean square deviation calculated from IPM profiles for different angles of electron beam.

During the electron cooling run we attempted to simultaneously perform profile measurements with both the IPM and the SPM. Since the expected event rate for the SPM at conditions typically present in COSY is about 10/s residual gas pressure had to be raised locally to get a reasonable signal to noise ratio. Unfortunately this attempt failed making the SPM profile measurement impossible. After the cooling run vacuum equipment issues were resolved and the profile measurement was carried out. To obtain reasonable signal to noise ratio residual gas pressure was intentionally increased to $5\cdot10^{-8}$ mbar at the SPM location only. Due to different machine settings, in particular the injection parameters, no direct comparison can be done. Figure 4 shows a vertical proton beam profile measured at injection energy. The beam current amounted to 2.82 mA.

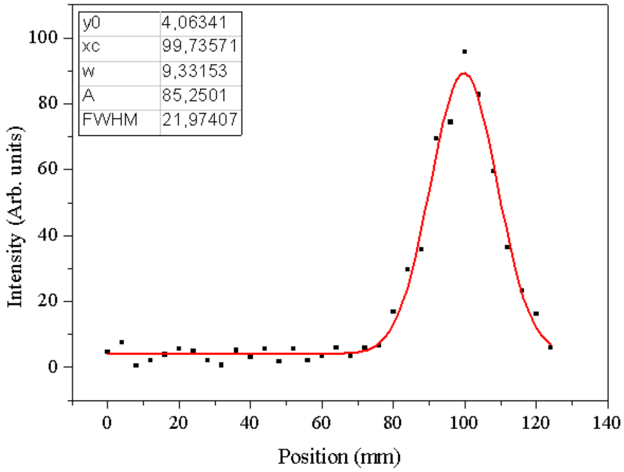

Figure 4: Vertical profile of an uncooled proton beam measured with the SPM shortly after injection. Beam current 2.82 mA, residual gas pressure $5\cdot10^{-8}$ mbar.

The results, shown in figures 1 and 4, were compared qualitatively taking into account that the beta functions at the locations of both instruments are equal. The profiles were found to be in reasonable agreement. A systematic cross-calibration is yet to be done.

SUMMARY

During the recent electron cooling beam studies at COSY the new IPM was used extensively. In fact, it was the recent commissioning of the IPM that triggered the scheduling of the electron cooling beam studies.

Reliable operation of the IPM was demonstrated. Online data analysis and graphical representation were found adequate. The IPM allowed for time saving optimization of the electron beam alignment. This was done by angle and position scans of the electron beam using corrector coils in the electron cooler, while observing the profile evolution. The 2σ transverse emittances of the electron cooled 0.4 mA proton beam at injection energy were estimated to be 0.3 µmrad in horizontal and 0.5 µmrad in vertical plain. The fact that vertical emittance is larger than the horizontal one may be due to the configuration of magnetic field in the cooling section. Similar behaviour was observed in the previous cooling runs. Longitudinal friction force measurements were carried out by introducing a 100 V step to the electron energy and recording the transition of the proton beam to a new horizontal position in a dispersive region (IPM). The results are in good agreement with the ones obtained using different method. However, the accuracy of the IPM based measurement is estimated to be higher.

From the experience with the IPM we conclude that electron cooling optimization in a machine like HESR, where no H^0-diagnostics can be used, can be performed solely based on data delivered by an IPM.

Though the current data acquisition rate of 24 fps appears to be adequate for electron cooling studies, installation of fast Ethernet cameras, supporting readout speeds up to 200 fps is planed. This may be helpful for investigation of fast beam losses and instabilities.

The attempt to measure the vertical profile using the SPM during the cooling run failed due to issues with the vacuum equipment. However, measurement at a later time was successful demonstrating good performance of the SPM. A local pressure bump had to be introduced at the SPM location to enhance the signal to noise ratio. The required pressure is much lower than the one induced by internal targets routinely operated in COSY. Though the qualitative comparison of the SPM data with the IPM one shows good agreement, systematic comparison of the results obtained with the two profile monitors is yet to be performed.

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