THE PROTON SYNCHROTRON DESY III

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Abstract

Desy III is one link in the chain of injectors for HERA, the electron/positron - proton colliding beam storage ring. Because of the relatively low injection (kinetic) energy of 50 MeV space charge plays a significant role in determining the achievable accelerated current. The luminosity in HERA is critically dependent on the transverse beam brightness hence the need to examine, and where possible minimise, emittance blow-up. Measurements of the beam emittance as a function of intensity in Desy III and the derived incoherent space charge tune shift are presented and discussed. Finally some preliminary investigations with regard to upgrading the injection energy via a pre-booster are described.

1 INTRODUCTION

The Desy III synchrotron accelerates protons from a momentum of 0.31 MeV/c to 7.5 GeV/c in approximately 2s. Injection is from a 50 MeV H^- Alvarez linac using charge exchange in a thin (34μg.cm^{-2}) carbon foil. The linac output current is around 14 mA with a variable pulse length set in normal operation to 33μs corresponding to ten turns. The RF system consists of a single, ferrite tuned, cavity operating between 3.2 and 10.3 MHz providing harmonic number 11. Transition is not crossed during the acceleration ramp. The original design requirement was for an output intensity of $1{\cdot}10^{11}$ particles per bunch equivalent to some 165 mA circulating in 11 bunches. In routine operation some 10% more current is achieved while the maximum observed current corresponds to 25-30% above the design value. Although the longitudinal bunch area specified in the original proposal[1] is achieved, the assumptions regarding transverse emittance have yet to be met. This is the main topic reported on here.

It should be noted that injection and subsequent acceleration is accompanied by particle loss. The injection efficiency, measured as the ratio of the charge circulating immediately after the n-turn injection compared to that contained within the linac pulse, is 85% to 90%. Thereafter about 55% of this beam survives until full energy with the losses confined to the first 250 ms of the acceleration cycle ie ceasing after a momentum of circa 1 GeV/c. This transmission behaviour does not depend upon the number of injected turns below that required for the maximum achievable intensity.

The occurrence of longitudinal bunch oscillations has been reported elsewhere[2]. A feedback system[3] is installed which damps the dipole modes but is only activated during the magnet flat-top when the revolution frequency is constant. The threshold for the onset of the oscillations is around an intensity equivalent to 60 ma in flat-top Thus during acceleration the observed beam horizontal profile at higher intensities is somewhat influenced by radial synchrotron oscillations and to a much lesser extent by bunch shape oscillations. Although the shape oscillations are not damped by the feedback there is a negligible contribution to longitudinal mismatch at extraction and injection into Petra, the next accelerator in the injector chain.

2 EMITTANCE MEASUREMENTS

Desy III is equipped with residual gas monitors to measure the beam profile in each plane and a single wire scanner to measure the horizontal profile.[4] Both systems produce a beam profile resulting from a time integration. The residual gas monitor is based on the readout of a video camera whilst the wire scanner traverses at $\sim$1 ms^{-1}. Comparison of the profiles yielded by each system at peak energy show excellent agreement.[5]

The residual gas monitors, which measure the average profile on 4 consecutive cycles, have been used to acquire profile data over a wide range of beam intensity and momentum. The first conclusion is that there is a blow-up of the emittances in both planes between injection (flat bottom) and full energy (flat top). This is shown in Figures 1 and 2. where the horizontal and vertical emittances are plotted as a function of accelerated current. Due to the transmission losses already mentioned even if no blow-up occurred there would be a factor of $\sim$2 reduction in the phase plane density.

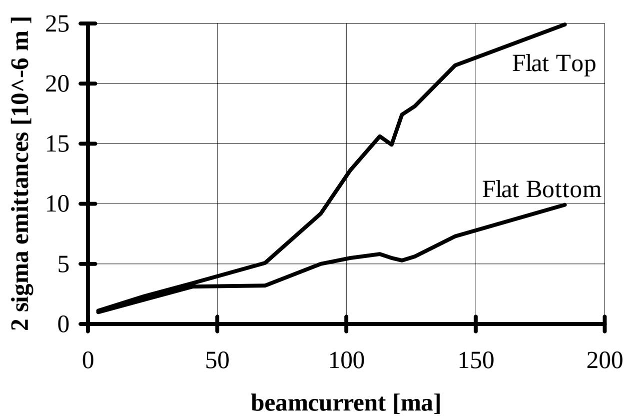

Figure 1: Horizontal emittance vs accelerated current.

Measurements of the emittances at the exit of the linac, using charge deposition on wire harps, yield ε_h =

$3.2{\cdot}10^{-6}$m and ε_v = $2.5{\cdot}10^{-6}$m for the horizontal and vertical *normalised, 2σ* emittances respectively. To within the measurement errors, which may be of the order of 25%, the same values are recorded in flat bottom for at most 2-turn injection. No increase in emittance could be detected for 2-turns with up to an additional 20 passages of the proton beam through the stripping foil. At this low intensity there is no evidence of emittance blow-up between injection and top energy.

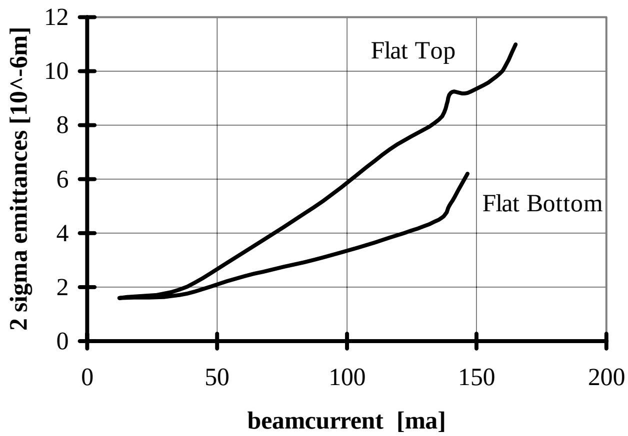

Figure 2: Vertical emittance vs accelerated current.

The injection of further linac turns leads to a recorded emittance at injection which increases approximately linearly with current. There is an additional blow-up during acceleration which also shows an approximately linear increase with intensity, rising to a factor of ~2 under standard operational intensities.

3 TRANSVERSE SPACE CHARGE

Space charge is considered to be the most significant effect limiting the maximum achievable beam brightness. We may write the expression for the vertical detuning as:

$$\Delta Q_v = \frac{N r_p F G}{\pi \varepsilon_v \left(1 + \sqrt{\frac{\varepsilon_h}{\varepsilon_v}}\right) B_f \beta \gamma^2} \quad (1)$$

Where N is the total number of circulating protons, r_p = classical proton radius, F (~ 1) takes account of the image forces, G ($\geq$ 1) is a transverse distribution factor, B_f is the bunching factor (average/peak current) and ε is the transverse *normalised, 2σ* emittance. The subscripts h and v refer to the two transverse planes.

Measurements of the (vertical) emittance as a function of time/momentum during the cycle together with the the bunch length allow the derivation of the tune shift. The bunch length is measured using a resistive wall monitor with bandwidth of order 1GHz. To evaluate ΔQ_v we have used F=G=1 in equation1 and for the bunching factor have assumed a parabolic line density which is in good agreement with measurements.

Figure 3 shows typical results for the vertical emittance versus time during acceleration for two different end intensities while figure 4 is a plot of the derived variation of the vertical tune shift for an end intensity of 180 ma. Although ΔQ_v has a maximum value of ~0.6 at the start of acceleration it is not clear that incoherent space charge effects are responsible for the blow-up observed during the whole cycle for high intensity beams. The initial phase space density of low current beams yields similar large tune shifts.

We have not observed coherent betatron oscillations during the acceleration cycle. We may speculate that the radial synchrotron oscillations, whose amplitude increases with increasing intensity and which are not damped until flat-top, impose additional good field requirements to maintain transverse emittance. Desy III is equipped with the minimum number of multipole magnets required to independently influence/compensate all 3^{rd} and 4^{th} order betatron sum resonances spanned by a space charge tune spread of 0.4. Skew quadrupoles are incorporated to correct the coupling. To date studies with these systems have been confined to achieving increased accelerated intensity. They are not activated in standard operation. Further studies of their influence on emittance are planned.

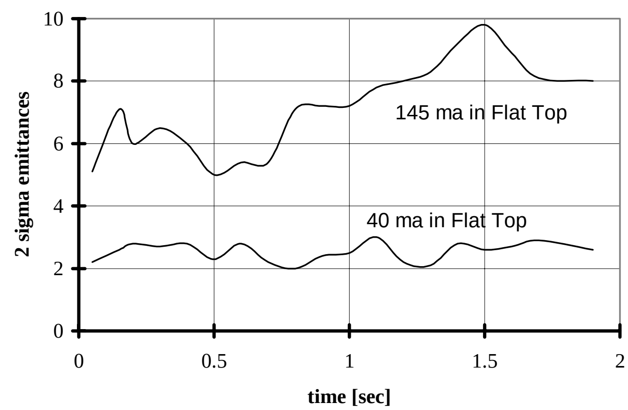

Figure 3: Vertical emittance vs time during acceleration.

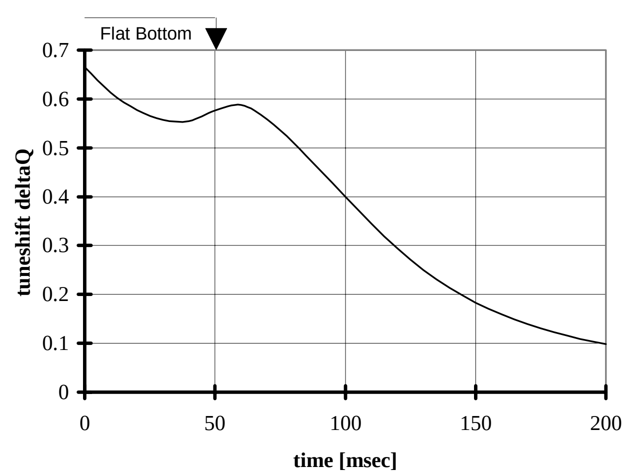

Figure 4: Derived (vertical) tune shift vs time.

4 UPGRADE OPTIONS

Short term improvements concentrate on reducing the observed losses. At present orbit correction is via dc-powered elements. It may be advantageous to incorporate time dependent correctors. We observe a systematic increase of the orbit radius shortly after the start of acceleration indicative of a dipole field tracking error. Improved read-out electronics for the position monitors are essential and system tests are underway.[6]

A study has been made of increasing the injection energy using additional linear accelerator structures in the space between the present Alvarez linac and the synchrotron tunnel.[7] An increase of injection energy to 170 MeV is considered feasible. This would theoretically reduce the space charge tune shift, at constant phase space density, by a factor of 2.

Somewhat more promising is a study in progress based on the use of an intermediate booster.[8]. Sited in the existing building alongside the present linac this would accelerate 2 bunches to 800 MeV kinetic energy using a 1 Hz magnet cycle which is the maximum repetition rate of the linac. The space charge tune shift in the booster would be moderate and that in Desy III reduced by a factor of 3 to 5 depending on the chosen bunch intensity.

Use of such a booster requires bunch to bucket transfer to Desy III using fast (ca. 70 ns risetime) kickers. The ten bunches would be boxcar accumulated using 5 booster transfers. Measurements have been made on an 800 MeV flat-top in Desy III which gave a beam lifetime of 270 s and no observable emittance increase over 2.7 s. The additional accumulation time produces a negligible increase in the overall Hera filling time.

5 ACKNOWLEDGEMENTS

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