ELECTRON DYNAMICS AFTER THE HERA LUMINOSITY UPGRADE

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Abstract

DESY is currently working on decreasing the size of the proton beam and of the electron beam in HERA at the collider experiments H1 and ZEUS by moving quadrupoles closer to the interaction points and by increasing their strength. To match the smaller proton beam size, the horizontal electron emittance has to be decreased by changing the damping partition numbers and/or by an increase in the phase advance per FODO cell. Together with reaching design currents, these measures should increase the luminosity of HERA from the current maximum value of 2 to $7.6 \cdot 10^{31}$cm^{-2}s^{-1}.

An increase from the current $60°$ to $72°$ phase advance per FODO cell in both planes which reduces the horizontal emittance from 41 to 30nm and a further reduction to 20nm by a shift of the rf frequency have been analyzed and found to have satisfactory properties in computer simulations both with and without chromatic correction.

Experimental tests have been carried out to find whether an increase of the rf frequency reduces the emittance as predicted and whether the current rf frequency is close enough to the center frequency to allow for the required increase. Additionally tests of whether the increased focusing reduces the emittance as predicted and whether the dynamic aperture remains satisfactory in a $72°$ optics have been made.

Finally, the reduction of the emittance has to lead to an increased specific luminosity and therefore experience with e/p collisions for a $72°$ electron optics will be described.

1 ELECTRON EMITTANCE IN THE HERA LUMINOSITY UPGRADE

In the HERA luminosity upgrade it is planed to obtain a luminosity which is 5 times higher than the original design luminosity of $1.5 \cdot 10^{31}$. To achieve this luminosity of $7.6 \cdot 10^{31}$, the proton beam size has to be decreased by moving the proton final focus quadrupoles from currently 26m to 11m from the interaction point (IP) [1, 2, 3, 4]. This in turn requires a very early separation of the electrons from the proton beam. This is achieved by moving superconducting combined function magnets into the detector up to 2m from the IP. The early separation of the beams is simplified by a narrow electron beam and therefore the electron emittance is planed to be reduced from currently 41nm to 20nm [5, 6, 7].

This emittance reduction should be achieved in two ways: changing the damping partition numbers by increasing the rf frequency and by making the focusing stronger in the FODO cells. An rf frequency shift changes the energy of the electrons and makes the beam travel along a dispersive orbit, which has curvature in quadrupoles. However, reducing the transverse emittance ϵ_x by a change in the damping partition numbers increases the energy spread σ_δ of the electron bunch.

If one does not want to compromise on particle loss out of the rf bucket, the relative rf bucket height $\Delta E/E_0 \cdot 1/\sigma_\delta$ has to be increased accordingly. This will be done by decreasing the dispersion η in the arcs of the ring via an increase of the horizontal focusing from currently $60°$ to $72°$ per FODO cell. By doing so, an additional fact comes in very handy: stronger focusing additionally reduces the emittance. For HERA it turned out that a focusing of $72°$ per FODO cell together with a frequency increase of about 300Hz for the 500MHz cavities leads to the desired emittance and to an unchanged relative bucket height.

2 DYNAMIC APERTURE

It was fond that going to $90°$ phase advance per FODO cell in order to reduce the emittance by more focusing alone leads to a strongly reduced dynamic aperture due to the stronger sextupoles which are required for chromaticity correction [5].

An investigation of several focusing possibilities [7] showed that a $72°$ optics has the most promising dynamic aperture. The dynamic aperture for the only slightly varied HERA electron optics used over the last three years was always in a band between the 23σ and the 31σ horizontal and vertical emittance when simulated with MAD. The vertical emittance was assumed to be $\varepsilon_x/2$, which has proved to be a useful assumption for other high energy electron rings. This band of the simulated dynamic aperture for the current ring is displayed as a yellow band in the dynamic aperture figures 1 and 3.

The on energy dynamic aperture of the presented lumi upgrade optics is as large as the current dynamic aperture as shown in figure 1. The linear optics however becomes unstable for negative energy shifts of more than about -0.5% if the tune is not rematched. This restriction can be avoided when the linear optics is made less energy dependent by means of a chromatic correction with different sextupole families. The variation of the dynamic aperture with energy deviation can also be reduced by such a correction.

3 CHROMATIC CORRECTION

In a $72°$ optics the phase increases by $360°$ after every 5th FODO. With one x and one y sextupole in each FODO,

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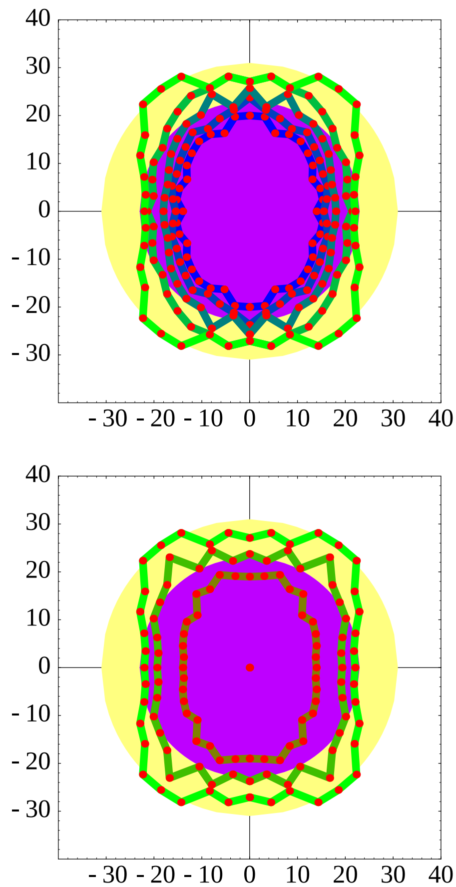

Figure 1: The boundaries of stable motion in x and y shown in units of beam sigmas for the 72° lumi upgrade optics with rf frequency shift for energy deviations top: from 0% (green) to 1% (blue) in intervals of 0.25%, bottom: from 0% (green) to -0.5% (red). An energy shift of -0.75/tune is not rematched.

every 10th sextupole belongs to the same family. In the current 60° optics there are six free families with 24 sextupoles per plane and octant. To have 4 sextupoles in each of the 10 families per octant, the last 8 sextupoles in each octant are switched off. There are 64 possibilities to wire the three power-supplies to the five sextupole families per plane and octant.

By employing a very efficient scheme of finding the sextupole strength for the chromatic correction with differential algebra techniques, they were computed for all of these 16 times 64 possibilities. Those possibilities for which the average square of the sextupole strength is minimal were used to compute the chromatic beta beat correction of figure 2. The corresponding dynamic aperture is shown in figure 3. While the on energy dynamic aperture becomes smaller due to stronger sextupoles, the dynamic aperture changes less with energy and the linear motion does not become unstable for negative energy shifts.

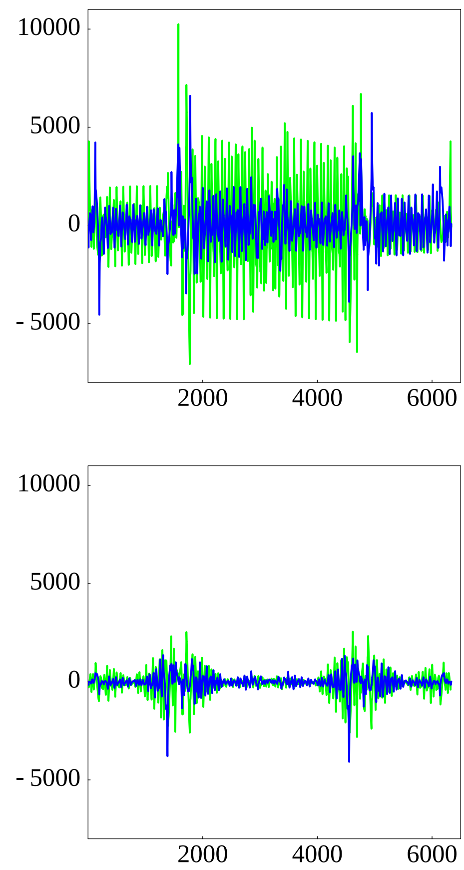

Figure 2: The energy dependence of the beta function $\partial_\delta \beta_x$ and $\partial_\delta \beta_y$ before chromatic correction (top) and after chromatic correction (bottom). The beta beat is matched to zero at the IPs and at the center of the arcs.

4 TESTS WITH THE CURRENT HERA

Several test have been performed with the current HERA electron ring in order to find whether the described concept of emittance reduction lives up to expectations.

The feasibility of stronger focusing was studied by implementing an electron optics with 72° phase advance per FODO cell in the current HERA. Injection into this new optics, accumulation, ramp, and installing luminosity was unproblematic and the lifetime was 15h as usual. Scans of the luminosity in this optics against a separation of the two beams reviled a horizontal emittance which had decreased at least as expected. This scan also reviled a vertical electron spot size at the IP which corresponds to 22% emittance coupling, whereas this coupling was measured to be 5% for the current 60° optics. For this reason the 72° optics did not lead to a sufficient luminosity increase and in further accelerator studies the vertical spot size will have to be decreased by vertical dispersion correction and by decoupling of x and y motion.

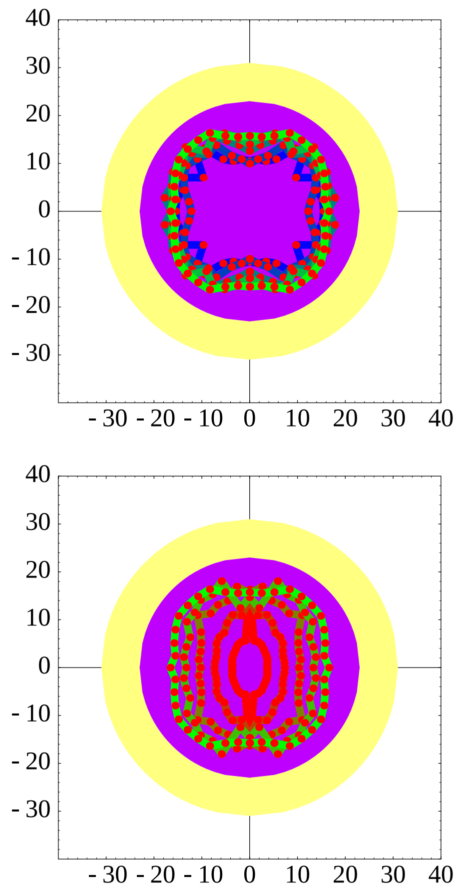

Figure 3: The boundaries of stable motion in x and y shown in units of beam sigmas for the $72°$ lumi upgrade optics with rf frequency shift and chromatic correction for energy deviations top: from 0% (green) to 1% (blue) in intervals of 0.25%, bottom: from 0% (green) to -1% (red).

The feasibility of a frequency shift was studied. There is a leverage for decreasing the emittance by increasing the rf frequency only if the current operation rf frequency f_0 is not too far above the central frequency f_c. Several experiments were therefore performed to specify a possible shift of the current rf frequency away from f_c [6, 7, 8, 9]. The current frequency was measured to be by about 150Hz too low, so that there is sufficient margin to increase it by the required amount. After taking this too low rf frequency into account, the spot size of the synchrotron beam decreased according to prediction when the frequency was varied. Since the systematic error of the spot size measurement are not well known, it was used as a fit parameter [8]. Ultimately the luminosity should increase when the emittance is reduced by a increased frequency. The relative increase in luminosity is shown in figure 4 and agrees with predictions for the H1 and ZEUS luminosity monitors.

Dynamic aperture measurements were performed [9]. For the current $60°$ optics the dynamic aperture was measured to be well above 10σ. A larger dynamic aperture

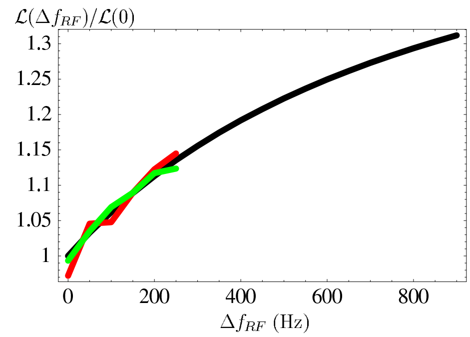

Figure 4: Relative increase in luminosity when the emittance is reduced by an rf frequency shift.

could not be measured due to a lack of kicker strength. For a $72°$ luminosity optics in the current HERA ring no chromatic correction was applied so that all horizontal and all vertical sextupoles had the same strength. The dynamic aperture was measured to be approximately 12σ by kicking the beam until half of the current was lost. All these results show that the $72°$ optics should be suitable for the luminosity upgrade.

5 REFERENCES

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