PETRA BUNCH ROTATION

Wilhelm Kriens
Deutsches Elektronen-Synchrotron, DESY, Hamburg, Germany

Abstract

The upgrade of the Petra *bunch rotation* scheme for protons will be described. Bunch compression in Petra is necessary for stable longitudinal transfer matching with Hera. The influence of beam loading in Petra has to be taken into account for currents above 50 mA even though a strong fast rf feedback system is installed. Amplitude modulation in a short push-pull cycle is chosen for *bunch rotation* and a bunch length compression factor of 0.7 is established with tolerable distortion.

1 INTRODUCTION

Proton transfer from Petra to Hera at 40 Gev/c with regard to longitudinal phase space matching using a 52 MHz rf system in both machines is somewhat critical [1].

Even with an optical change in Petra [2] (γ_{tr} = 6.2 to 7.9) the rf voltage ratio for matching is rather unfavourable.

$$\frac{(\ h\ |\eta|\ )_{\mathrm{Petra}}}{(\ h\ |\eta|\ )_{\mathrm{Hera}}} \;=\; 7.7 \tag{1}$$

The voltage in Petra is limited to 150 kV for short term operation. Therefore the voltage in Hera for matching (20 kV) is too low for stable beam injection.

Choosing to operate Hera at 100 kV during injection, requires longitudinal bunch compression by a factor of 0.66.

2 BUNCH COMPRESSION

The first scheme for *bunch rotation* comprised a 180 degree phase jump, a dwell period during which the bunch lengthens, a jump back to the original stable phase followed by about a quarter synchrotron period before beam transfer [3]. Since the transfer is determined from synchronization with Hera, the start trigger for the phase jump is prepared a fixed number of revolution turns before transfer. Although the procedure could be optimized to achieve adequate compression at moderate beam currents, above 50 mA (some 40 % of design) beam loading effects degraded the ideal behaviour. In particular the bunches became distorted during the phase jump.

In order to reduce beam loading effects, amplitude modulation was applied to the rf system inducing quadrupole mode oscillation for bunch compression. For this purpose a voltage controlled attenuator device with small phase deviation is used at low power input. Additionally the time constant of the transmitter gain control had to be increased to pass the modulation. The choice for the modulation cycle depends on the ability of the rf system and was optimized in relation to beam dynamics. The result can be seen from figure 1. A typical bunch in Petra is measured just before *rotation* and in the last turn at transfer.

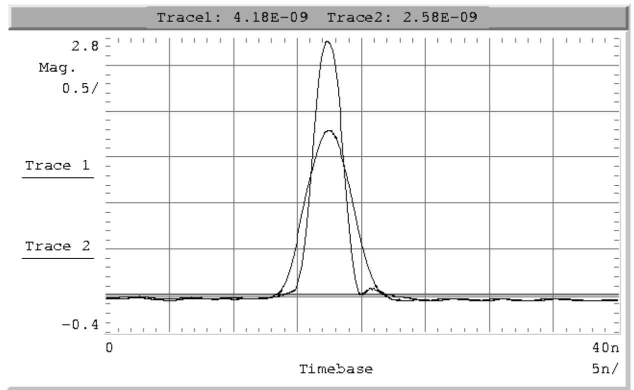

Figure 1: Bunch display just before *bunch rotation* (Trace 1) and the same bunch at extraction time (Trace 2).

2.1 PETRA RF System

Two 52 MHz cavities of the same type with independent power transmitters are installed [4]. Therefore careful phasing for power balancing is necessary to get the required circumferential voltage. In this case the total rf system can be simplified as shown in figure 2 to calculate the beam loading effects.

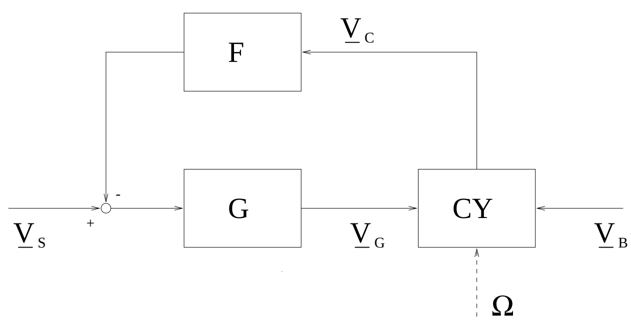

Figure 2: Block diagram of the Petra rf system with G the transmitter gain and F the feedback factor. Voltages $\underline{V}$ are in complex notation. Ω is the detuning value of the cavity CY.

The transmitter forward voltage $\underline{V}_G$ can be expressed in terms of the cavity voltage $\underline{V}_C$ and the beam voltage $\underline{V}_B = \frac{R_0}{2}\underline{I}_0$. From figure 2 we get the relation between the low level input voltage $\underline{V}_S$ and $\underline{V}_C$ directly.

$$\begin{aligned} \underline{V}_G &= \underline{V}_C + i\Omega\underline{V}_C + \underline{V}_B \\ &= (\underline{V}_S - F\underline{V}_C)G \end{aligned} \tag{2}$$

The detuning value $\Omega = Q_0\frac{\Delta\omega}{\omega}$ has settled prior to *bunch rotation* i.e.
$\underline{V}_B = -i\Omega\underline{V}_{C0}$ and $\underline{V}_{C0} = \underline{V}_{G0}$ with $\varphi_B = 0$.

Introducing the modulation index $\underline{m} = \frac{\underline{V}_S}{\underline{V}_{S0}}$ and assuming $FG \gg \Omega$ ($FG \approx 100$) we get

$$\frac{\underline{V}_C}{\underline{V}_{C0}} = \frac{\underline{m}(1+FG)+i\Omega}{1+FG+i\Omega} \approx \underline{m} \tag{3}$$

$$\frac{\underline{V}_G}{\underline{V}_{G0}} = \frac{\underline{V}_C}{\underline{V}_{C0}}(1+i\Omega) - i\Omega \approx \underline{m}(1+i\Omega) - i\Omega \tag{4}$$

From equation 3 we can see that the cavity voltage is proportional to the input voltage due to the strong fast feedback. Therefore the low level modulator directly controls the cavity voltage as desired but the power transmitter is disturbed by beam loading corresponding to equation 4.

With $V_{C0} = 140\,kV$, $R_0 = 2\,M\Omega$ and 70 mA of average beam current the detuning value is $\Omega = 1$.

If we suppose that the transmitter could deliver a factor of two more power for short term modulation, then 35 mA for phase jump ($\underline{m} = -1$) and 130 mA for amplitude modulation ($\underline{m} = 1.3$) are the beam current limits for operation. Both computer simulations and the reality in Petra has shown that $\underline{m} = 1.3$ is sufficient for bunch compression via amplitude modulation.

2.2 ESME Simulation

The ESME computer program [5] was used to optimize the operation mode for amplitude modulation of the cavity voltage. The aim was to get a minimum compression factor for the bunch length with tolerable distortion of the emittance.

Due to the ability of the rf transmitter the simulation is done with a modulation cycle as shown in figure 6. It can be seen that fast ramping of the voltage up and down with twice the synchrotron frequency is the best way to quickly induce shape oscillation. The maximum voltage corresponds to $\underline{m} = 1.3$ and the minimum voltage is found to be symmetric with respect to the starting value.

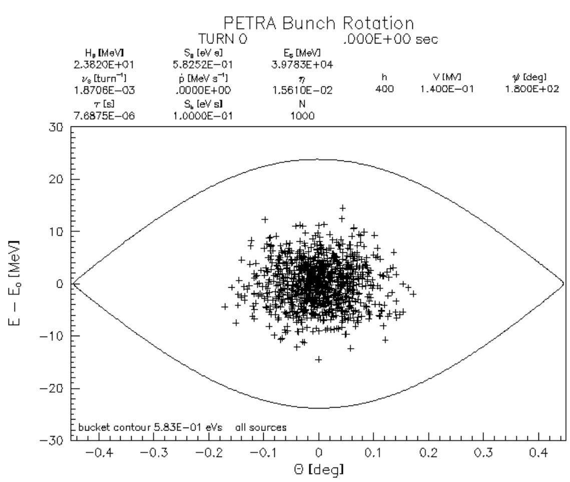

Figure 3: Initial bigaussian Phase Space Distribution.

For the special case of 0.1 eVs emittance and a bigaussian distribution (see figure 3) we get the evolution of the bunch length and the distortion of the emittance turn by turn as seen in figure 7 and figure 8. The optimum timing for beam transfer is at turn 440 after three quarter synchrotron oscillations. Only for rather low emittance more *rotation* cycles are useful. Figure 4 displays the phase space at turn 440 in our special case.

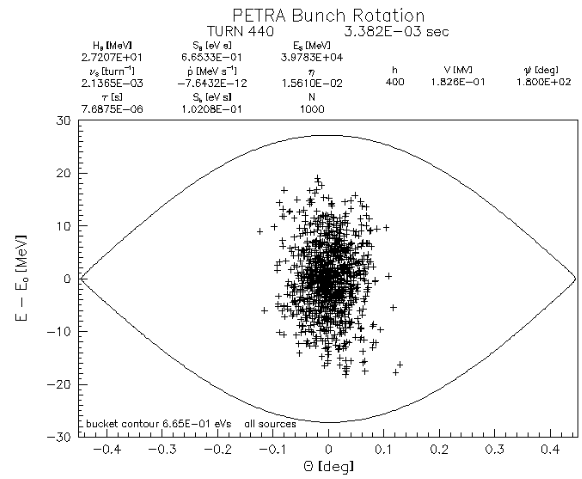

Figure 4: Distribution at Transfer (turn 440).

To illustrate the bunch oscillation more impressively a mountain range display of the bunch length is shown in figure 5.

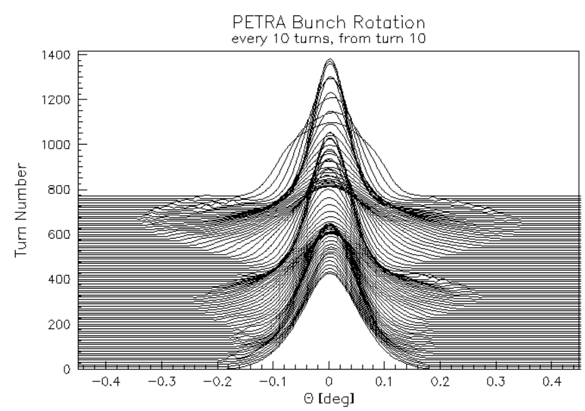

Figure 5: Mountain Range Display of the Bunch length.

Table 1 shows the influence of the initial emittance on the *bunch rotation* based on a bigaussian phase space distribution. Bunch compression fulfills the Hera requirement for stable injection with less than 5 % of distortion.

Furthermore it can be seen from the simulation that the modulation parameters are not very sensitive. Therefore a tuning of these values is not foreseen in the operation control.

Table 1: Compression and Distortion vs initial Emittance.

Emittance	Bunch length	Compression	Distortion
[eVs]	FWHM [ns]	[ ]	[%]
0.04	1.74	0.652	0.2
0.06	2.15	0.646	0.6
0.08	2.49	0.647	1.2
0.10	2.80	0.653	2.1
0.12	3.09	0.668	3.4
0.14	3.33	0.686	5.0
0.16	3.61	0.717	7.4

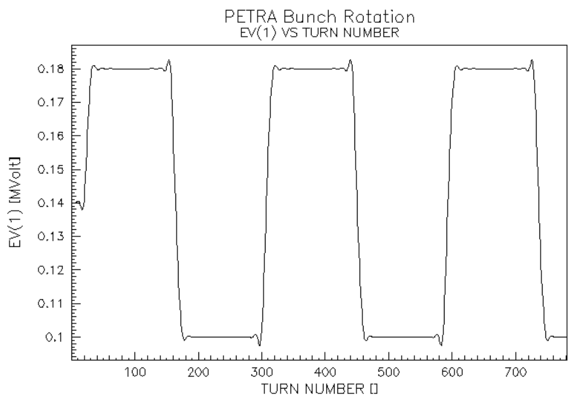

Figure 6: Cavity Voltage Modulation.

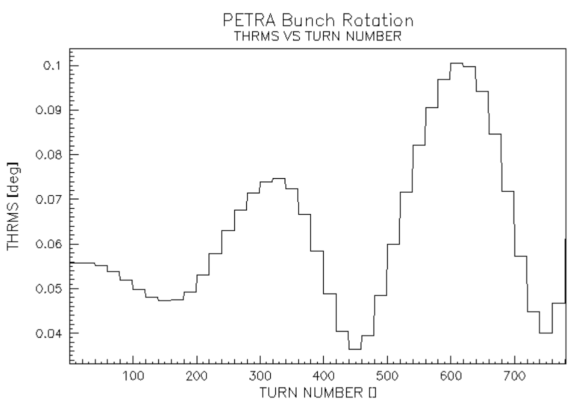

Figure 7: Bunch length (THRMS $\times$ 50 ns $\approx$ FWHM).

3 ACKNOWLEDGEMENT

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4 REFERENCES

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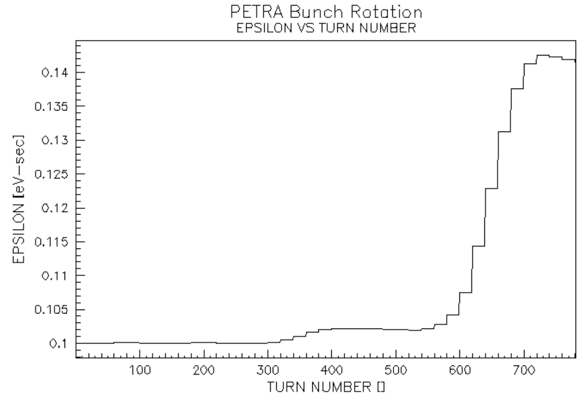

Figure 8: Emittance growth.

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