ONE NANOSECOND BUNCH COMPRESSOR FOR INTENSE PROTON BEAMS*

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Abstract

About ten micro bunches out of a 2*MeV* proton rf-linac with an average current of 150*mA* at 175*MHz* will be deflected by a kicker with a repetition rate of 250*kHz* on different paths into a magnetic bending system. Passing this optimized geometry they approach each other longitudinally ($\beta\lambda = 0.114m$) and arrive at the same time at the focus of the compressor. For longitudinal focussing of the micro bunches rebuncher cavities are included in the bending system. The peak current is expected to be in the range of 7.5*A* with 7.7*nC* in a 1*ns* proton pulse at the target, which is equivalent to a longitudinal compression ratio of 45.

The motivation and the layout of the whole project, "Frankfurt Neutron Source at the Stern-Gerlach-Zentrum" (FRANZ), were presented in details in contributions to previous conferences [1,2] and in an other contribution to this conference[3]. More accurate investigation of the bunch compressor geometry results in a revision and improvement of the preliminary concept. Single path trajectories along a new compressor layout were simulated with the multi particle code PARMILA[4]. In this paper the beam dynamics results from PARMILA-simulations and the new geometry are discussed.

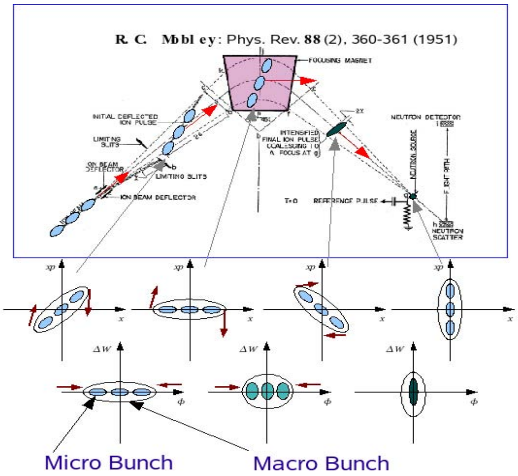

Figure 1: Bunch compression of 2MeV mono-energetic proton pulses in µA-range due to path differences of the trajectories and "weak focussing" of a dipole. (Mobley-type bunching)

GEOMETRY: 1-DIPOLE-SYSTEM

In the original paper[5] a dc-proton-beam in the *µA*-range is deflected by an electric kicker on different paths. While transverse focussing by "weak focussing" of the dipole the chopped bunch is compressed longitudinally by path difference between the head and tail of the chopped bunch. This 1-dipole-geometry and schematics of the phase-rotation of this concept are shown in Figure 1. In this concept a set of three parameter (**L**,**R**,α) is enough to define all properties of the system. **L** is the distance of one focus to the symmetry axis, **R** is the radius of curvature of the homogenous dipole and α is the angle of the trajectory with respect to the symmetry axis. For a fixed **L** either the magnetic field or the shape of the dipole has to be varied in order to map all bunches from one focus to the other for arbitrary α. Characteristics for both options of this 1-dpiole-system are:

- Long drifts without focussing element.
- Sensitivity of the center orbit to the shape of dipole edge.
- Dipole edges not free to choose for beam dynamics.
- Small distance between the trajectories at the edge of the dipole.
- Limited linear operation range.

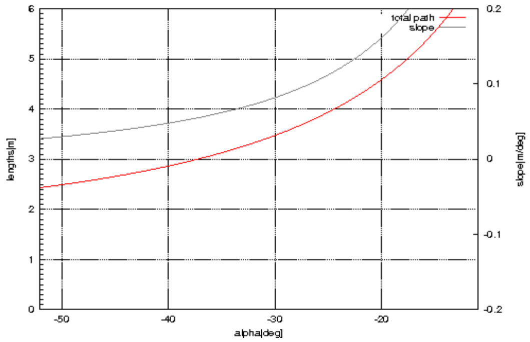

Figure 2: total path lengths of the 1-dipole system as function of the angle α. For L=1m and R=0.38m. The total path is strongly non linear for region with adequate path differences. The "slope"=Δ(total path)/Δα is non constant. This property will be inherited in the kicker amplitudes and other geometrical properties, e.g. distances of the trajectories at the dipoles edges.

These properties increase the challenge to handle low velocity (β=0.06), high intensity proton bunches. Therefore all possibilities have to be utilized to keep the

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transverse and longitudinal bunch size under control. The most natural way in this system to control the transverse beam dynamics is focussing by dipole edges. Such a system needs more flexibility in the geometrical lengths and distances between the trajectories.

GEOMETRY EXTENSION FOR INTENSE PROTON BEAM

Due to the discussed difficulties following concepts have been studying in detail since EPAC '06:

- ***2-dipole-system***: 2 skew magnets with gradient.
- ***3-dipole-system***: 2 homogenous skew magnets and 1 skew magnet with gradient on the symmetry axis.
- ***4-dipole-system:*** 2 homogenous sector magnets and 2 sector magnets with gradient.

In order to decrease the free drift length multi-dipole bending systems are preferred. The opportunity to manipulate the transverse beam dynamics is increased by any additional dipole edge. In systems with skew magnets the main contribution of path difference is outside of the dipole and the paths within the dipole remain almost constant for all trajectories. The mapping from one focus to the other focus of the bending system is given by transverse gradient of the dipoles. Therefore all edges of these systems are free parameter for beam dynamics. In the 2-dipole and the 3-dipole system the path lengths and the distances at the dipole edges can be well defined by the geometrical parameters of the system. But the path differences per angle differences and the magnitude of gradient in the dipole is far challenging to adjust.

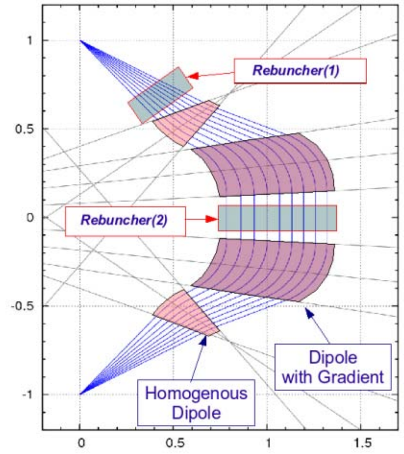

Figure 3: Schematic of one setting of the 4-dipole system.The tics of the axis are in distances of 0.1m.

A 4-dipole-system with sector magnets seems to be sufficiently flexible to fit to all critical requirements for the bunch compressor:

- **max. drift $< 0.8m$**
- **$\Delta B < 0.1T$**
- **$\Delta\alpha_{i,i+1} \approx$ const.**
- **$\Delta\alpha_{max} < 20deg$**

On the other hand the set of free parameter $\{\alpha, (\alpha_{m1}, \alpha_{s1}, p_{x1}, p_{y1}, R_1), (\alpha_{m2}, \alpha_{s2}, p_{x2}, p_{y2})\}$ of the system is much bigger than that of the Mobley-concept. For each sector magnet a set of at least 4 parameters is needed to describe this object completely. α_s is the angle between the edges of the sector and α_m is the angle of the symmetry axis of the sector magnet with respect to the symmetry axis of the whole system. p_x and p_y are coordinates of the corner of the sector. R_1 is the radius of curvature of the homogeneous dipole and α is the angle of the trajectories with respect to the symmetry axis. One possible setting is plotted in Figure 3. The magnetic field in the dipole with gradient, the total path of the trajectories and the angle differences are shown in Table 1 and in Figure 4.

Table 1: Some Properties of the Scheme show in Figure 3.

α [deg]	$\Delta\alpha_{i,i+1}$ [deg]	B_2 [T]	t_p [m]
-28.00	1.93	0.6112	3.5706
-29.93	2.01	0.6195	3.4564
-31.94	2.11	0.6276	3.3421
-34.06	2.24	0.6355	3.2279
-36.30	2.40	0.6430	3.1137
-38.70	2.59	0.6502	2.9995
-41.30	2.83	0.6568	2.8853
-44.13	3.12	0.6627	2.7710
-47.25	-	0.6678	2.6568

All geometrical parameters and the magnitude of the magnetic gradients of this setting are promising. But the final design can not be decided until a careful study of the multi particle beam dynamics with multi bunch interaction has been performed.

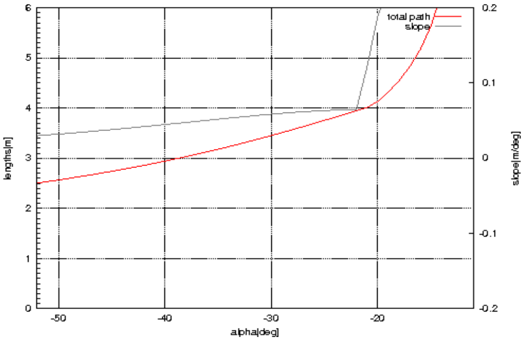

Figure 4: Total Path Lengths of the 4-Dipole System as Function of the Angle α. The total path is more linear in the region of interest in compare to the 1-dipole-system in Figure2. The kink in these curves is due to the corner of the homogenous dipole.

BEAM DYNAMICS

The complicated geometry and beam properties of the discussed system do not allow an accurate simulation of the whole system by common LINAC-design programs. For a proof of principle the transport of single bunch along individual trajectories was calculated by PARMILA.

Ideal 3σ-distributions with realistic emittances [2] of the beam after the main LINAC is taken as input for a simulation through 3.57*m* beam line with 4 dipoles (see **Figure 5-6**). For longitudinal focussing 2 rebunchers have to be included. The first one is located in front of the first dipole and the second is located on the symmetry axis of the bunch compressor. The first rebuncher operates with 175*MHz* and the voltage amplitude is 85*kV*. Due to the phase spread of the bunches after 1.7m transport the second rebuncher has to operate at 87.5*MHz* at similar amplitude. For transverse beam dynamics the dipole edges are optimized to reach a beam spot about 3×3cm^2 at the target. The envelopes of the whole transport are shown in Figure 7-8.

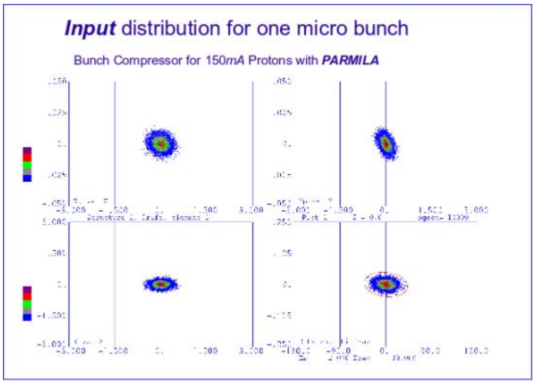

Figure 5: Input distribution for PARMILA. Emittances is taken from output of the main LINAC of FRANZ.The units of the axis are in cm/rad and deg/MeV.

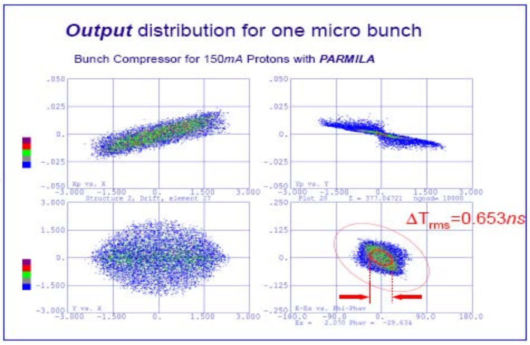

Figure 6: 1ns pulse length can be reached with the 4-dipol-system. But 2 rebuncher cavities have to be included in the bunch compressor. The first one is located in front of the first dipole and the second is on symmetry axis of the system.

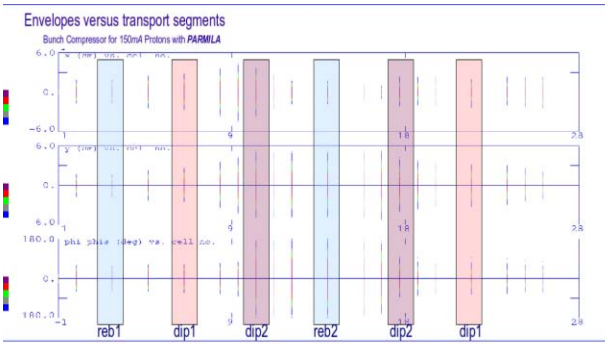

Figure7: (x, y, ϕ)-Envelopes. The light blue boxes represent the rebunchers, the orange boxes are the homogenous dipoles. The red boxes are the dipoles with gradient. The coupling between the x- and ϕ- plane due to the dispersion can be observed after segment: dip2.

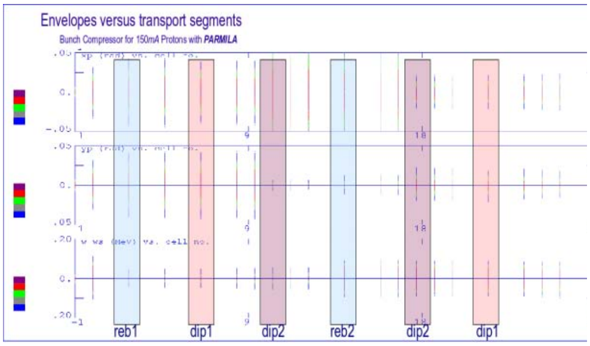

Figure 8: (xp, yp, ΔW)-Envelopes. The momenta exchange between the x- and y-plane due to dipole edge focussing can be observed in segment: dip2.

CONCLUSION

Due to the high beam current and about 1*m* long incoming bunch train a complex system of magnet and rebunching is needed to reach the final bunch lengths around 1*ns*. Transport codes specific to the bunch compressor geometry are needed, which are able to deal with this unique kind of micro bunch merging.

REFERENCES

[1] L.P. Chau et al., EPAC '06, Edinburgh, TUPLSO082, 1690-1692 (2006); http://www.JACoW.org.

[2] O. Meusel et al., LINAC '06, Knoxville, MOPO51, 159-161 (2006); http://www.JACoW.org.

[3] C. Wiesner et al., EPAC '08, Genoa, THPP111 (2008), http://www.JACoW.org.

[4] http://LANL.gov.

[5] R.C. Mobley, Phys. Rev. 88(2), 360-361 (1951).