BEAM DYNAMICS DESIGN PARAMETERS FOR KONUS LATTICES

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Abstract

The 'Combined Zero-Degree Structure' ('Kombinierte Null Grad Struktur - KONUS') beam dynamics concept has been successfully applied on several linacs, some of them in routine operation since decades. However, the KONUS lattice parameters optimization is often done in a results-oriented approach, depending on the designers' experience. This paper focuses on the description of the longitudinal beam motion along one KONUS lattice period. A test lattice is used for illustrating the effects of the variation of essential cavity rf and transverse focusing parameters on the KONUS beam dynamics design. The main objective of this ongoing work is to derive general rules for the parametrization of KONUS lattices.

DESCRIPTION OF THE 'KONUS' BEAM DYNAMICS CONCEPT

The KONUS concept defines separated function linacs, with a basic unit consisting of a multi gap main acceleration section with 0 deg synchronous particle definition, a short rebunching section at negative synchronous phase and a powerful transverse focusing element like a quadrupole triplet or a s.c. solenoid lens.

This setup provides effective acceleration close to the crest of the rf wave together with smaller gap rf transverse defocusing of the beam, and thus enables the use of multi gap cavities with high shunt impedances (slim drift tubes with no internal quadrupole lenses) at low and medium beam energies. Especially $\beta\lambda/2$ DTLs of the H-mode type ('IH' based on the H_{110} mode or 'CH' based on the H_{210} mode) take advantage of the KONUS concept, due to their rf and mechanical properties.

Detailed descriptions of the KONUS beam dynamics concept can be found in several publications, not least in text books on accelerators [1-4].

Recently our group at IAP/Frankfurt University carried out systematic investigations regarding the parametrisation of KONUS lattices, on the occasion of the design of KONUS and H-mode based proposals like the FAIR Proton Linac [5] or an GSI Alvarez main linac replacement [6], [7]. This paper can only provide an insight in the current, ongoing activities. More results will be published soon in a broader context.

For illustrating the functional principle of KONUS and the effects of several parameter variations, one part of the FAIR Proton Linac has been chosen as a test lattice, namely the second section of the first CH-DTL cavity. The simulation starts in the centre of the cavity-internal triplet lens and ends in the centre of the external triplet behind the CH-DTL. The accelerator structure consists of 3 rebunching gaps with Φ_s = -35 deg followed by 8 gaps with Φ_s = 0 deg. The input and output beam energies are W_{in} = 5.95 MeV and W_{out} = 9.91 MeV, respectively.

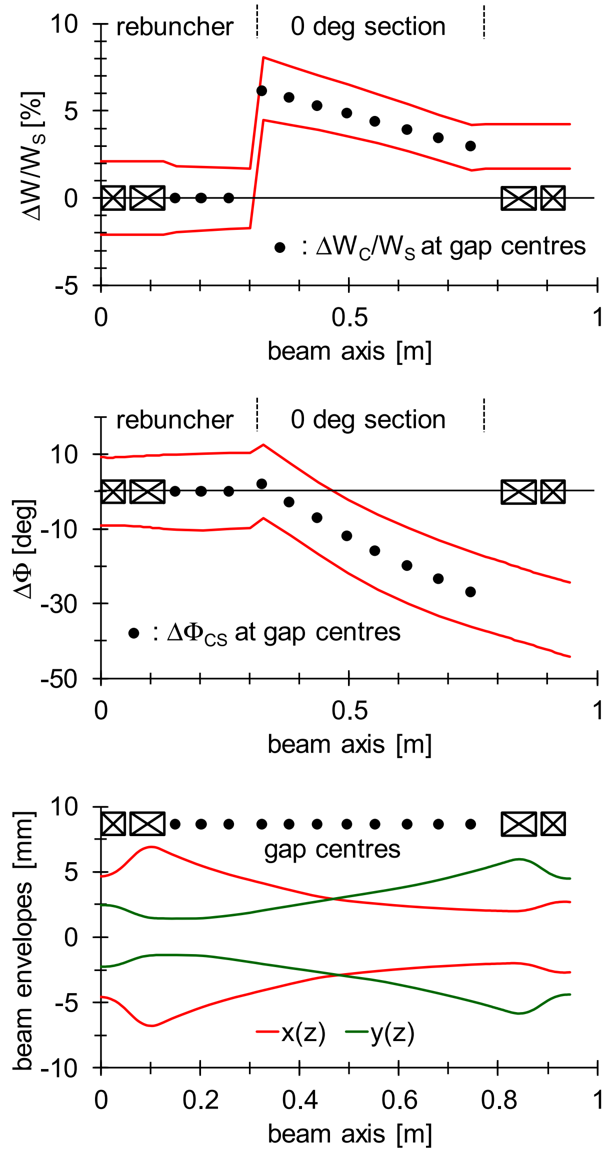

Figure 1: Test lattice beam envelopes (one KONUS section as used for the FAIR Proton Linac).

The average on axis gap fields are about $E_0 \approx$ 15 MV/m. Main geomet-rical lengths to be mentioned are $L_{triplet} \approx$ 250 mm and $L_{accelerator} \approx$ 660 mm. This numbers lead to average accel-eration gradients of 6 MV/m along the cavity, respectively 3.5 MV/m when including the lenses and inter tank drifts.

In Fig. 1 the evolution of the longitudinal and transverse beam envelopes along one KONUS period is shown: After passing the quadrupole half lens at the entrance, the beam is accelerated and longitudinally focused in the 3 gap conventional rebunching section. Energy and phase of the synchronous particle (index 'S') and of the

ISBN 978-3-95450-182-3

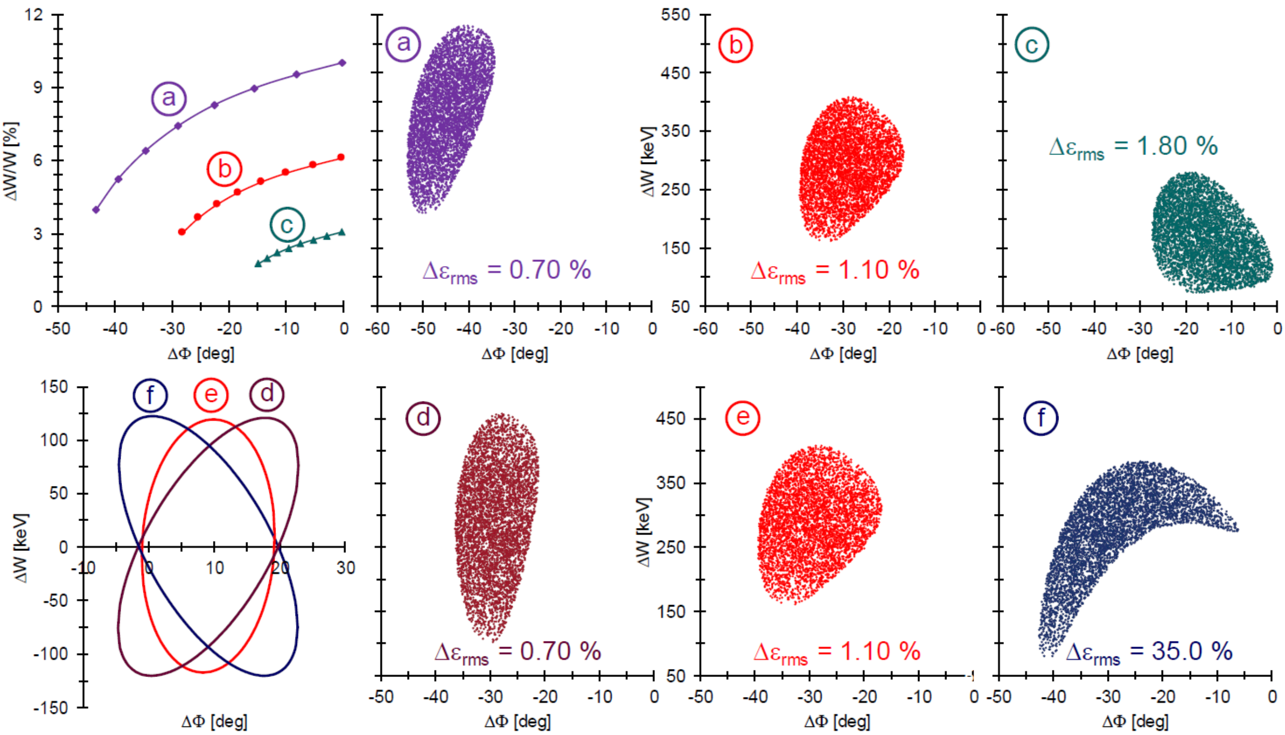

Figure 2: Variation of the surplus energy (upper line) and the beam orientation (lower line) at the entrance of the 0 deg section with resulting output particle distributions. The injected emittance is: ε_{tot} = 10 keV·ns, ε_{rms} = 2.5 keV·ns.

bunch centre (index 'C') are overlapping along this segment.

The apparent jump of the whole bunch in energy and phase at transition to the 0 deg main acceleration segment is due to the definition of a new synchronous particle. This is lower in energy than the real bunch by 6 % in the design case shown in Fig. 1. 'Technically' the asynchronous injection into the 0 deg section is realized by a longer drift at the transition cell (gap centres distance corresponding to 215 deg instead of 180 deg) and by defining the velocity profile (geometric period lengths) according to the new synchronous particle, lower in energy than the real bunch.

Due to this offset in energy and phase, the bunch follows the paths as shown in Fig. 1: It moves towards negative phases as far as $W_{BC} > W_S$ and loses surplus energy related to the synchronous particle, since the s.p. is at Φ_s = 0 deg by definition. Thus, stable motion in longitudinal phase space is provided, basically as long as the bunch moves within the second phase space quadrant.

DESIGN PARAMETERS OF THE LONGITUDINAL BEAM MOTION

The main design parameters with influence on the particle motion along a KONUS 0 deg section are as follows: Surplus energy $\Delta W = W_C - W_S$, beam ellipse orientation ('tilt' parameter α) and starting phase offset $\Delta\Phi_{CS} = \Phi_C - \Phi_S$ at the entrance of the 0 deg section, moreover the acceleration gradient (effective gap voltages V_{eff}) and the number of gaps.

The variation of the parameters ΔW and α is illustrated by the examples in Fig. 2 and will be discussed further below. As for the other parameters: $\Delta\Phi_{CS}$ at the entrance of the 0 deg section can be used for the fine tuning of the effect obtained by the ΔW variation. If the 0 deg section is located at the beginning of a cavity, $\Delta\Phi_{CS}$ can be even adjusted during operation (tank phase knob). For all examples shown in Fig. 2 the setting is $\Delta\Phi_{CS}$ = 0. The magnitude of V_{eff} has only influence on the step width of the bunch centre motion between neighboured gaps, and finally the maximum number of gaps per section is limited by the edge of the second quadrant ($W_{CP} = W_S$) and by the transverse beam dynamics (optimum distance between lenses).

In Fig. 2 the settings 'b' and 'e' correspond to the design values as used for the beam tracking results shown in Fig. 1. The upper line of Fig. 2 shows the effect of the ΔW variation from the design value of 6% to 10% (setting 'a') and 3% (setting 'c'). The resulting pathways in the longitudinal phase space are quite different, leading to output particle distributions with different beam energies, orientation (focused or defocused) and shape (emittance growth). The design optimum (setting 'b') shows a focused beam with preserved ellipse half axes ratio and moderate emittance growth. The higher ΔW is chosen (see setting 'a'), the faster negative bunch phases are reached towards the end of the 0 deg section. This helps for additional beam focusing and for avoiding emittance growth caused by the nonlinear sine function close to Φ_S = 0 deg. However, for setting 'a' the beam focusing is too strong, which can be seen in the resulting large energy spread.

This might cause matching problems into the next KONUS section. The optimum ΔW setting is depending on parameters like the bunch energy W_{in} and the design particle (A/q value). The optimum ΔW is decreasing with increasing W_{in}. More profound investigations on this topic can be found in ref. [8].

Finally, the orientation of the input distribution ('tilt' parameter α) is a very powerful design parameter, as illustrated in Fig. 2, lower line. At the entrance of a 0 deg section a focused beam is required. This implies a precedent rebunching section or an external buncher. A focused beam maintains a small phase spread along the 0 deg section entrance, and thus emittance values are kept small. With a defocused beam at the entrance the contrary happens (see results for setting 'f'), which can easily result in substantial emittance growth.

DESIGN PARAMETERS OF THE TRANSVERSE BEAM MOTION

Since KONUS lattices consist of multi gap sections (10 to 20 gaps typically) without internal focusing elements, powerful lenses are needed (usually located in the inter tank sections) for sufficient transverse focusing. By default, quadrupole triplets with alternating polarity are used, but also doublet channels or solenoids are possible.

Quadrupole triplets commonly have different focal lengths and corresponding phase advance values in the x and y plane. The focal length can be adjusted either by varying the B' value of each singlet individually or by keeping B' equal for all singlets of a triplet and varying the singlet lengths. The latest has been applied for the test lattice as presented in Fig. 1, with the design value B' = 58 T/m. In Fig. 3 the effect of the B' variation on the phase advances σ_x and σ_y is shown. The σ evolution is different in x and y and even a crossing is observed at B' = 64 T/m. This effect must be considered, but it is not a 'show stopper', as the lens polarity is flipping at the next KONUS period and so the average phase advance over several periods becomes similar for both planes.

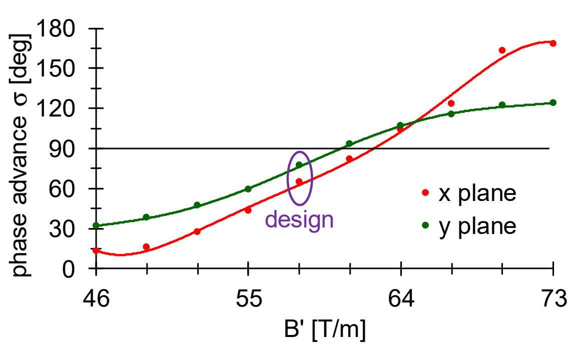

Figure 3: Phase advance for different B' values.

The relatively high design values for σ (around 70 deg in this case) are typical for KONUS lattices and are required by the much smaller lens filling factor as compared to conventional DTL designs in that energy range.

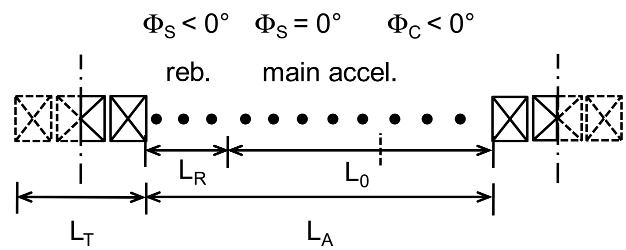

Figure 4: Simplified model used for KONUS parameters investigations.

OUTLOOK

In this paper, just a small excerpt of the ongoing activities of our group at IAP/Frankfurt University could be presented. Further details, especially on the description of the particle motion along the 0 deg main acceleration section, can be found in ref. [8] and several more detailed results will be published soon.

The main topics in preparation are a description of the bunch centre motion along the 0 deg section based on analytic approximations, as well as the parametrisation of one KONUS period by using a simplified model as shown in Fig. 4. In this model the ellipse transformation method is used and the main parameters are the lens gradients B', the gap fields E_0 and the geometric parameters lens filling factor (expressed by the ratio L_T/L_A) and the ratio between rebunching and main acceleration expressed by L_R/L_0.

One of the outcomes of this work will be the setup of stability charts for the particle motion in KONUS lattices, similar to the well-known Smith and Gluckstern charts valid for conventional designs [4].

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ISBN 978-3-95450-182-3