VALIDATION OF THE 700 MHZ TRASCO SC LINAC DESIGN BY MULTIPARTICLE SIMULATIONS

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Abstract

We present here the results of the preliminary simulation activities performed to validate the upgraded TRASCO linac design at 700 MHz, in the framework of the Franco-Italian collaboration. The beamline has been investigated with multiparticle simulations performed with different codes, and up to 100,000 particles, showing no halo formation and minimal emittance growth in the nominal case, in the absence of machine imperfections.

1 THE 700 MHZ LINAC

The motivations for the frequency change of the TRASCO linac are discussed in a separate contribution to these Proceedings [1]. Here, for sake of completeness, we just recall that the new frequency allowed setting a wide European collaboration, mainly based on common work and sharing of R&D activities between INFN, CEA and IN2P3. Following the frequency change of the superconducting linac to a value double than the lower energy part of the linac, the new beam line layout has been investigated, in parallel with the French colleagues [2], with the codes that we developed for the 3D space charge dominated beam dynamics in high current linac with elliptically shaped cavities [3] and that have been used in the past to analyze the 350 MHz option [4].

1.1 Linac Layout

The linac has been designed to bring the proton beam from an energy as low as 85 MeV (the minimal energy that can be captured with the lowest beta cavities) to a maximum final energy of 2 GeV, using three different beta sections, at the synchronous beta values of 0.5, 0.68 and 0.86 (the geometric beta values are 0.47, 0.63, 0.85, respectively).

The cavities accelerating field have been limited to guarantee peak surface magnetic fields lower than the conservative design value of 50 mT.

The transition energies between the sections have been loosely set to 200 and 500 MeV.

The doublet lattice periodicity in the three sections is 4.2, 4.6 and 8.5 m, and the quadrupoles are situated in the 1.6 m warm space between the cryomodules in the period. The cryomodules contain 2 five-cell cavities in the low and intermediate beta section and 4 six-cell cavities in the high beta section.

The synchronous phase is kept to the constant value of –30° along the linac.

The cavities in the first section operate at an average accelerating field of 7.4 MV/m and 20 lattice periods bring the beam energy to the transition to the second section. Here 27 lattice periods with cavities operating at an average accelerating field of 9.8 MV/m bring the beam to the last section. At the entrance of the last section the cavity gradient is reduced to achieve a smooth matching of the longitudinal beam tune and finally the last part of the linac is operated ad a constant energy gain of 11.4 MeV per cavity. The cavities in the last section operate at an average accelerating gradient of 11.8 MV/m.

1.2 Linear beam dynamics

The beam line design and matching has been analyzed with TRACE3D, TraceWin (from CEA/Saclay [5]) and a longitudinal design code we have developed. The cavity accelerating fields in the linac have been set in order to obtain a smooth longitudinal phase advance per meter. The quadrupole gradients have been calculated with TraceWin to avoid first order resonances between the longitudinal and transverse tunes, which lead to fast emittance exchanges between the two planes.

The phase advances of the matched beam for the average current of 20 mA are shown in Figure 1. Due to the lower frequency (352 MHz) of the intermediate linac (RFQ followed by either a DTL or a ISCL), the beam current in the simulations has been set to the peak value of 40 mA.

The matching between the sections is performed with the four quadrupoles and the RF cavity phases at the last and first lattice periods of the two consecutive sections.

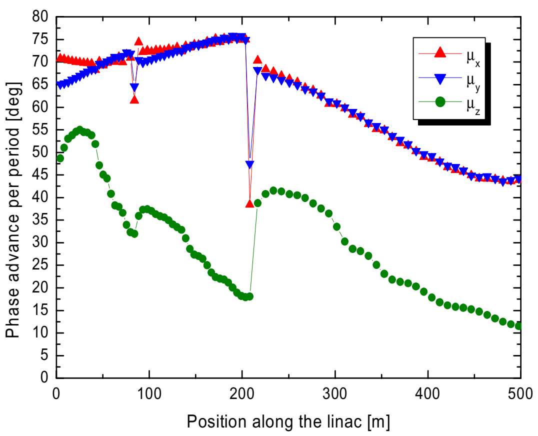

Figure 1. Phase advances for the matched beam along the 20 mA, 2 GeV SC linac.

2 MULTIPARTICLE SIMULATIONS

2.1 The SCDyn code

The beam dynamics code that we have written for the simulations of the SC TRASCO linac (SCDyn) advances particles in phase steps through the beam line elements of the linac. Analytical maps are used for the particle propagation in drifts and quadrupole elements, whereas a direct integration along the on-axis field of the RF cavities is performed (with a second order off-axis expansion to account for transverse focusing effects).

The reason for using such a cavity modeling technique, which is more cumbersome on the computational point of view with respect to a standard "thin gap" approximation, lies in the behavior of the cavity transfer matrix elements as a function of the particle energy. As we have shown in Reference [6], a cavity model based on a single thin gap fails to reproduce the cavity transfer matrix elements except for the particles at the nominal energy of the reduced beta structure.

The space charge calculations are performed with a cloud in cell charge deposition scheme and a 3D V-cycle multigrid [7] Poisson solver in the beam rest frame.

The SCDyn code is purely a beam tracking code and does not perform the beam line design or beam matching. For these purposes we use linear design codes, as TRACE-3D, or the TraceWin code. Both codes use a cavity model consistent with the SCDyn description.

2.2 Results

In Figure 2 we show the behavior of the rms beam sizes along the beam line, up to 1 GeV, corresponding to the same matched case of Figure 1. The sharp increase of the matched beam size in the last section, due to the big difference between the lattice periods (4.6 m in the second section and 8.5 m in the third), does not lead to a beam emittance increase, as it will be shown in the following figures, but allows a drastic increase of the linac filling factor.

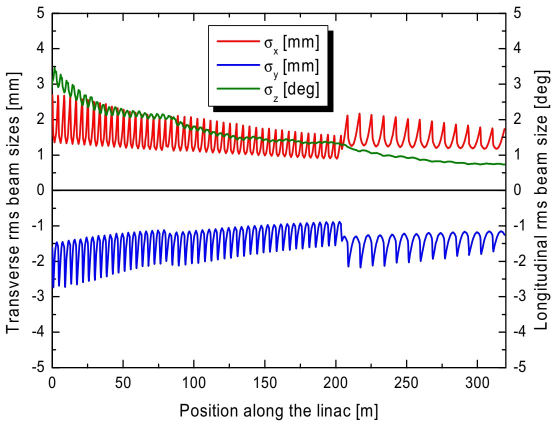

Figure 2. rms beam sizes in the matched SC linac, up to 1 GeV, from the multiparticle simulations.

The simulations were performed with 50,000 particles with a time step of 4 RF degrees and space charge kicks every 20 time-steps.

The cavity bore sizes increase from 40 mm to 50 mm in the three sections, and the ratio of the aperture radius to the rms beam size ranges from 15 to 25.

Figure 3 shows the rms normalized emittances along the linac. The top panel shows the relative rms emittance variation from the initial value. A small emittance exchange between the planes can be seen, leading to a 5% increase of the longitudinal emittance and a 2% decrease of the transverse. Most of the emittance exchange occurs in the first section, possibly due to the non-stationary nature of the initial distribution under the space charge forces (we used a 6D uniform waterbag).

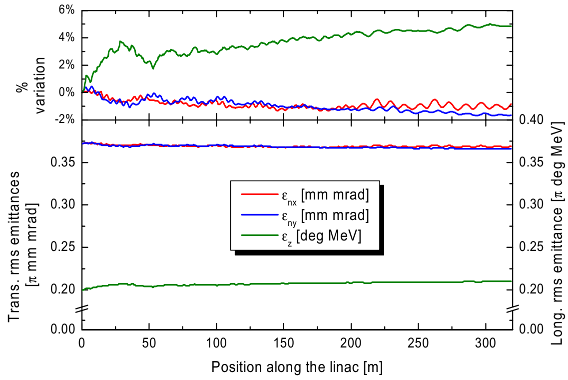

Figure 3. rms normalized emittances in the linac.

The beam is well matched along the entire linac. As an indication to this in Figure 4 we plot the particle population in the phase space. This figure shows the beam fraction contained in a given ellipse area normalized to the rms emittance value, for the initial and final beams. No alterations of the particle distribution can be seen up to the emittance containing 90% of the beam, while the last 10% of particles is driven to outer phase space regions. The total (100%) emittance of the initial distribution in the case of the 6D waterbag is 8 times the rms value, while the total emittance of the final distribution reaches a value of about 10 rms.

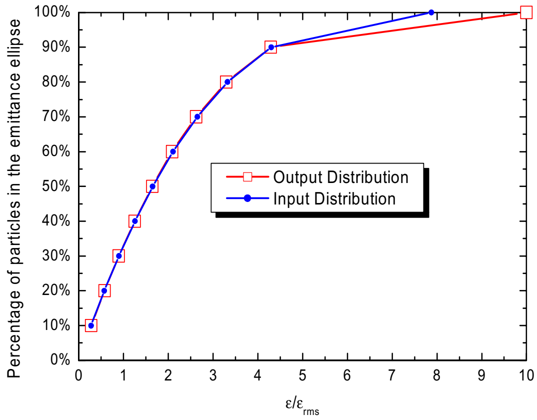

Figure 4: Particle distribution in phase space, for the input and output beams.

As another indication of the good beam matching in Figure 5 we show the behavior of the horizontal beam radii enclosing a given beam fraction (90%, 99%, 99.9% and 100%), divided by the horizontal rms beam size, as a function of the position along the linac. The 90% beam radius is very smooth and only the last 1% tail of the beam distribution shows mismatching oscillations.

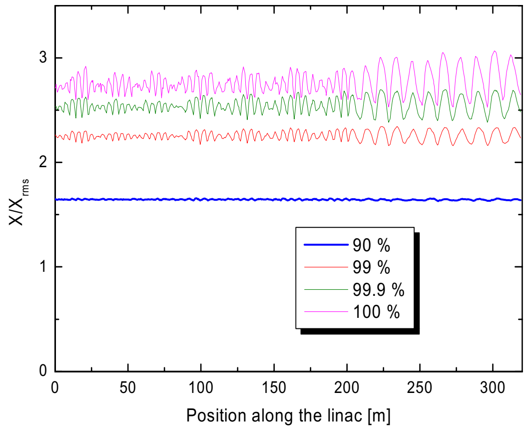

Figure 5: Normalized beam size (beam radius containing a given particle percentage divided by the rms size) as a function of the position along the linac.

Finally, Figure 6 shows the phase spaces of the output beam from the SCDyn simulations. The two ellipses drawn on the phase spaces indicate the rms emittance and 4 times the rms. The characteristics rectangular shape of a space charge dominated beam can be clearly seen in the horizontal phase space (top left).

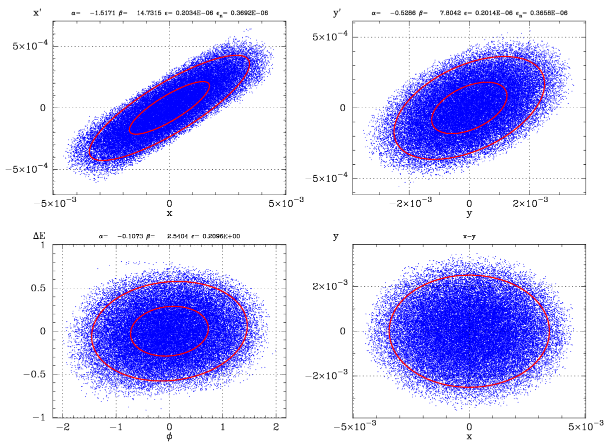

Figure 6. Output beam at 1 GeV (50 k particles simulation). Units are meters and radians for the transverse phase space, degrees and MeV for the longitudinal phase space.

2.3 Comparisons with Parmila

The same simulation (with 50k particles) has been performed with a version of Parmila in which N. Pichoff of CEA/Saclay added [5] a transport element with the same cavity modeling as SCDyn. The results are comparable, PARMILA predicts a longitudinal emittance increase of only 2% and a small oscillation of the transverse emittance. However, PARMILA does not show any correlated emittance exchange between the planes after the first section as in Figure 3 (See Fig. 7). This may be related to the 2D vs. 3D space charge modeling.

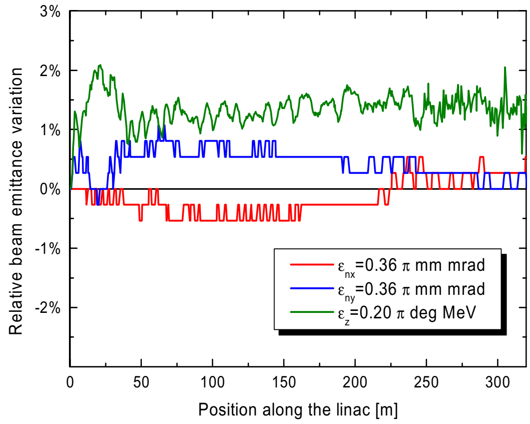

Figure 7: Relative emittance variations from PARMILA.

3 CONCLUSIONS

We presented here the preliminary beam dynamics analysis of the TRASCO SC linac. The frequency of the SC linac has been doubled to 700 MHz, as described elsewhere in these Proceedings [1], increasing the accelerating fields, in order to reduce the linac length and cost. No indications of substantial emittance growth can be seen from the simulations performed so far, in the absence of machine errors or imperfections. Extrapolation from the work done on the 350 MHz scheme [4] allows us to be confident that moderate beam mismatches can be tolerated with no halo formation and beam losses.

REFERENCES

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