THE 3D BEAM DYNAMICS WITH THE SPACE CHARGE IN THE LOW AND MIDDLE ENERGY SUPER-CONDUCTING OPTION OF HIPPI

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Abstract

For the low and middle energy of the High Intensity Proton Pulse Injector (HIPPI) a superconducting option is considered.The 3D beam dynamics simulation results in the Slot and the Finger-Slot sections covering the energy range from 3 to 160 MeV are presented. The optimization aim is the increase of beam current together with the reduction of emittance growth, beam losses and costs. The slot structure is compared with the conventional spoke structure.

LOW ENERGY RANGE 3-20 MEV

The usage of a conventional superconducting structure just after RFQ for acceleration of high intensity beam is complicated because of focusing problems in transverse plane. This caused by the long focusing period. For the low energy part, when the beta is small the cold-warm transitions occupy significant part of the focusing period. On the other hand, together with the high accelerating gradient in the superconducting linear accelerator the defocusing factor is high. To improve the focusing one can increase the transverse phase advance either by the quadrupole strengths increasing or by the focusing period length decreasing. Because of stability problems the phase advance per focusing period is restricted by the limit of 90°. The focusing period can be shortened only due to the smaller number of accelerating gaps per period. However in this case the real estate gradient of the structure becomes lower, and the longitudinal motion is strongly perturbed by the drift. One of the solutions could be the installation of superconducting focusing elements into one cryostat together with cavities. It allows excluding the cold-warm transitions and therefore significantly decreasing the focusing period length.

Another possible solution is to use the RF-focusing structures (see Fig. 1) [1]. In this H-structure the TE211 mode is used. The electric field quadrupole component, which is caused by the slots, is partly compensates the defocusing factor. The additional RF electrodes, installed on the extreme slots and the cavity ends, provide the necessary focusing in the transverse plane. Therefore the normal conducting focusing elements can be excluded together with cold-warm transitions. To increase the transverse phase advance and decrease its dependence on the longitudinal plane the FOODDOOF lattice type is suggested to be used. It is realized when every second cavity is rotated around the longitudinal axis.

The beam dynamics simulations of 40mA proton beam from 3 up to 21 MeV were performed, and they showed that at the synchronous phase -20° and the average gradient 1.7MV/m the longitudinal motion is linear and the particle losses are absent.

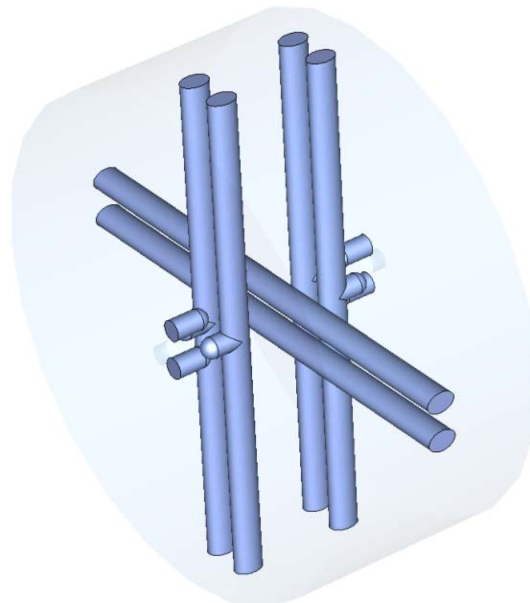

Figure 1: Slot-finger structure.

LOW-MIDDLE ENERGY RANGE 20-90 MEV

Begining some relative velocity β~0.2 we can refuse the RF focusing in order to provide the higher accelerating gradient without the focusing features worsening. For this energy range one of the most widespread superconducting structures is the spoke cavity structure. However, for this beta range the defocusing factor still plays the significant role in the beam dynamics. Therefore we developed the simpler structure based on the slot-geometry (see Fig. 2) [1].

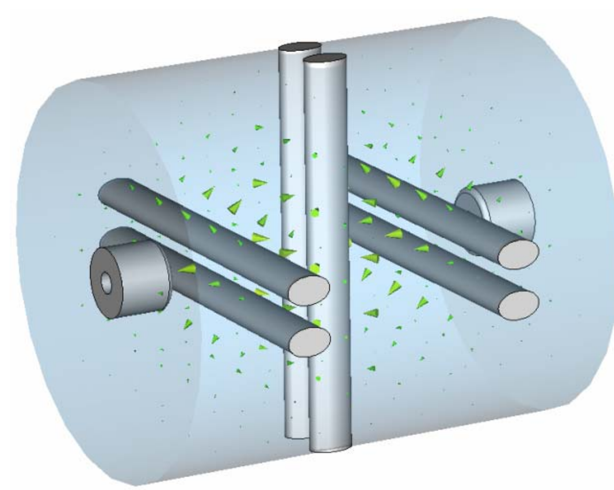

Figure 2: Slot structure.

The main distinction of this structure from the spoke structure is the partly compensated defocusing factor due to the electrical field quadrupole component. This one increases transverse phase advance by ~25% with the same quadrupole gradients for this energy range. Besides, it has the simpler shape for manufacturing.

On the other hand the transverse phase advance in this structure weaker depends on the longitudinal particle position than in the structure with the axial field symmetry in the region of the beam axis. Another difference of this structure is the absence of the welding near to the beam axis where the electric field component has the maximum. The main electro-dynamical parameters such as Epeak/Eacc and Bpeak/Eacc for this structure in the given energy range is similar to the spoke structure parameters.

To investigate the beam dynamics the simulation of 40mA proton beam from 21 up to 91 MeV was performed. Two family types of cavities were used for the accelerating channel β_{str} =0.246 and β_{str} =0.348. The Table 1 shows the main lattice parameters. Figure 3 shows the emittances and envelopes behavior.

Table 1: Main parameters of accelerating channel

Focusing type	FODO
Cavity number	29 (11+18)
Length	38.05
Real Estate gradient	1.84 MV/m
Average trans. phase advance	45-37°/m
Trans. rms emittance growth	<2%
Long. rms emittance growth	<0.5%

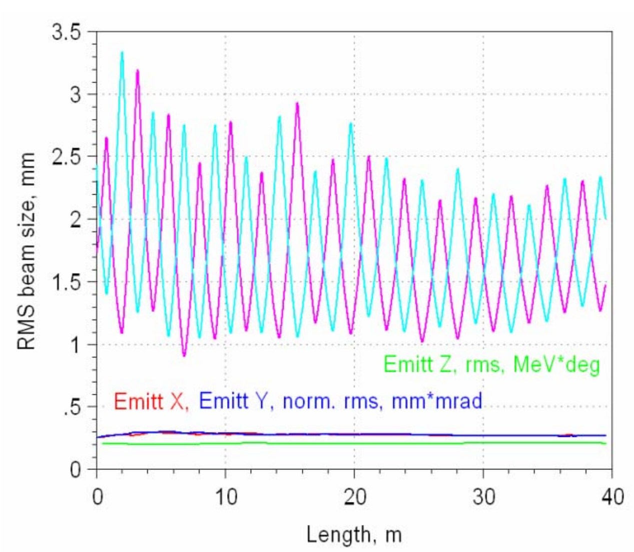

Figure 3: Beam envelopes and emittances behaviour.

MIDDLE ENERGY RANGE 90-180 MEV

With the higher beta the defocusing factor influence on the beam dynamics is weaker. For this energy range the most appropriate parameters for the structure comparison are the accelerating gradient and the manufacturing simplicity. However the comparison of accelerating gradient is not as straightforward as it looks at a glance. The problem is that the different structures have the different maximum reachable field values. In the relative velocity range around 0.46 the slot structure slightly yields to the spoke cavities by the electro-dynamical parameters. And the attempts to reach the same parameters lead to the significant complexity of the cavity (see Fig. 6). For this beta range this complexity is not justified by the higher accelerating gradient.

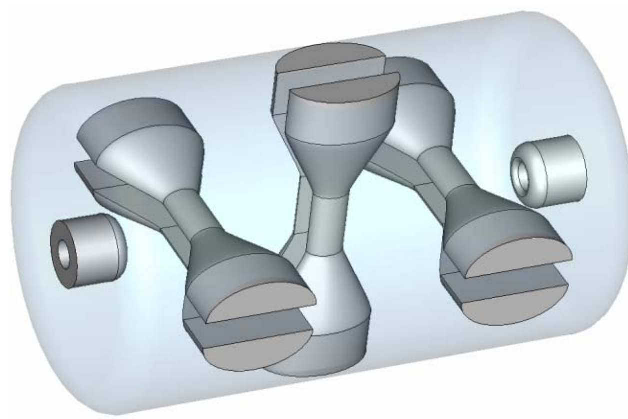

Figure 4: Slot structure type with improved electro-dynamical parameters.

To estimate the structure capability the beam dynamics simulations were performed in the same focusing channel with the different cavities. The simulations show that in this energy range there is no big difference in the beam dynamics between the spoke and slot structures. The comparison of the energy gain in the slot structure with the different field limitations and the spoke structure is shown on figure 5. The emittance growth in both structures is insignificant (see Fig. 6 and 7).

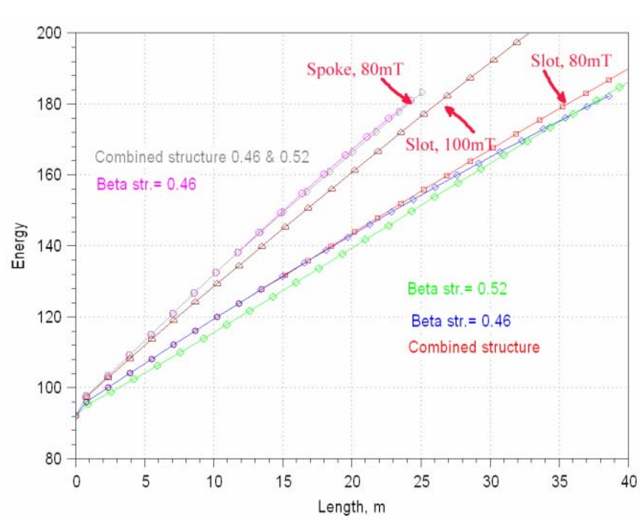

Figure 5: Energy gain in slot and spoke structures.

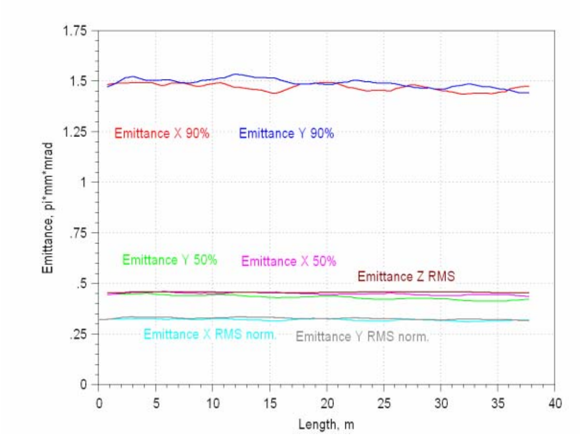

Figure 6: Emittances behaviour in slot structure.

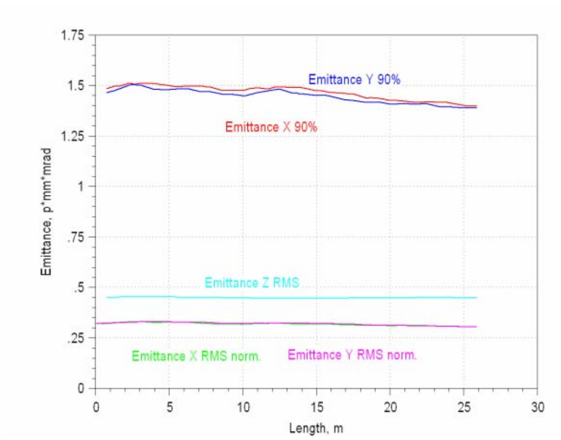

Figure 7: Emittances behaviour in spoke structure.

SUMMARY

The different superconducting structures were analyzed for the high intensity proton linac for the low and middle energy. For the low energy range 3-20MeV, just after RFQ, the slot-finger structure is the best candidate. For the intermediate energy range 20-90MeV both the slot and spoke structures are applicable. The slot structure is more preferable in case of the extreme peak current values because it supplies the additional focusing term, which is caused by the quadrupole electric field component. The choice of structure for the middle energy range should be based on the costs and the technological analysis of both structures, since there are no significant differences in the beam dynamics.

ACKNOWLEDGEMENTS

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[1] Yu.Senichev and N.Vasyukhin, “Slot-finger Superconducting structure with RF focusing”, Phys. Rev. ST Accel. Beams, **8**, 070101, (2005). ISSN 1098-4402.