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DESIGN OF THE RFQ-DTL MATCHING SECTION FOR THE SSCL LINAC*

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Abstract

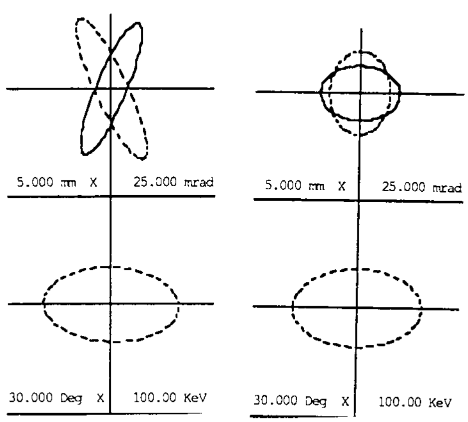
The paper presents the details of the physics design of the RFQ-DTL matching section of the SSCL linac. The 2.5 MeV H^- beam from the RFQ is matched into the acceptance of the 70 MeV Drift Tube Linac (DTL). For a nominal beam of 27.5 mA with a normalised (r.m.s.) transverse emittance of 0.2 mm.mrad. an emittance growth of about 5% is estimated at the end of the DTL. The behavior of the system with respect to the various type of beams and its sensitivity to fabrication and alignment errors has been analysed. A steering mechanism to align or position the beam anywhere within the acceptance of the DTL is also briefly explained.

Introduction

The SSCL linac is designed to give a 600 MeV H^- beam having an adjustable pulse width from 7 to 35 μsec and a repetition rate anywhere from 1 Hz to 10 Hz [1]. The nominal beam at the end of the RFQ will have an energy of 2.5 MeV and a beam current of 27.5 mA. Theoretically this beam is expected to have a normalised transverse emittance (r.m.s.) of 0.2 mm.mrad. The phase space of the beam at this end is shown in Fig. 1a. The goal is to match this beam to the acceptance of the DTL, the phase space of which is shown in fig.1b. The Twiss parameter β for the transverse planes is in units of mm/mrad and for the longitudinal plane is in deg./keV. This goal for matching is to be achieved with the following objectives. Firstly, the design should exhibit a minimum acceptable emittance growth. Secondly, it should have enough built in flexibility and versatility to accommodate some minimum permissible changes expected in the beam and its parameters. Thirdly, there shouild be a provision for incorporating some minimum necessary diagnostics, for observing and studying the beam behavior. The paper describes the salient features of the design procedure worked out for the RFQ-DTL matching section and reports the results

Design Approach

The six dimensional phase space of the beam is completely defined by its six Twiss parameters. The approach is based on finding the optimum solutions to the six variables to satisfy the six constraints, consisting of these six Twiss parameters. Matching of α_x, βx, α_y, and βy, the four Twiss parameters in the transverse planes, is designed to be taken care of by the four quadrupole magnets whereas the two buncher cavities take care of the longitudinal Twiss parameters α_z and β_z. The magnetic field gradients of the quads and the voltages of the cavities are the six variables for which the optimum solutions are sought . The drift spaces between the quads and the lengths are kept fixed for a given solution. To restrict the solutions to meaningful practical values, the quad gradients are confined to a maximum value of 100 Tesla per meter and the voltage for the cavities is kept within a maximum value of 200 kV. To keep the emittance growth within the permissible limit of about 5% for the nominal beam, every effort is made to keep the matching section as short as possible. But at the same time for understanding and getting the complete picture of the beam, enough space has been provided to accommodate minimum necessary beam diagnostic devices. Based on the reasoning given above, in Fig. 2 is shown the conceptual scheme. The Q's denote the position of the quads having lengths as L's. The D's are the drift spaces between them. The G's denote the position of the RF gaps. The design is worked out and analysed by using the computer codes, TRACE 3D [2], PARMILA [3] and TRANSPORT [4].



(a) (b)

	α (a)	β (a)	α (b)	β (b)
x	-1.590	0.173	0.009	0.287
y	1.730	0.199	-1.189	0.143
z	0.005	0.534	-.0005	0.482

Fig. 1 The phase space and the Twiss parameters.

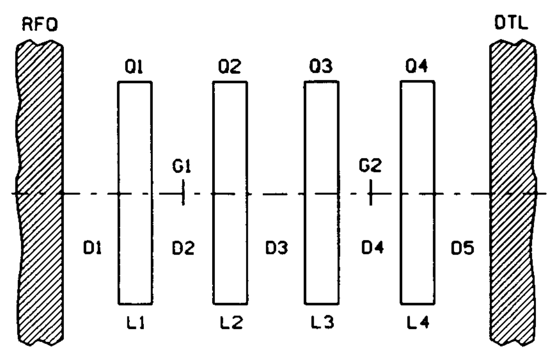


Fig. 2 The schematic of the matching section.

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Results

The detailed beam dynamics studies were carried out to check for the beam matching and the emittance growth. About 40 systems were studied and analysed. Table 1 gives the set of five design systems which not only gave perfect matching but also the results of which are close to the required limit of 5% for the emittance growth.

TABLE 1
Emittance Growth and the Design Parameters

D	QP	VBC	EG1	EG2
50, 90, 70, 90, 50	38, 38, 38, 38	0.14, 0.15	2.5	4.5
	-88.1, 88.4			
	-94.0, 86.8			
65, 90, 100, 90, 65	40, 35, 35, 40	0.14, 0.15	2.8	5.3
	-75.7,85.8			
	-90.2,76.8			
80, 90, 80, 90, 80	40,35,35,40	0.13,0.14	3.9	5.3
	-66.5, 85.0			
	-88.0, 68.9			
50,90,100,50,90	40,35,35,40	0.15,0.16	2.2	5.2
	-88.4, 98.2			
	-98.5, 96.8			
80, 90, 80, 90, 80	40,40,40,40	0.13,0.14	4.2	5.3
	-66.5, 74.0			
	-76.9, 69.0			

In Table 1, D stands for the spacings as explained in Fig. 2. QP denotes the quad parameters. The first row under QP gives the lengths of the quads and the next two rows denote quad gradients. VBC is the voltage on buncher cavities in MV. EG1 and EG2 give the percentage emittance growth at the end of the matching section and the DTL respectively. All the sets give almost the same emittance growth but the fifth set is the optimum one. The cavity voltages and the quad gradients are not only much lower than the specified limits but are also lowest among the five sets. This set has been

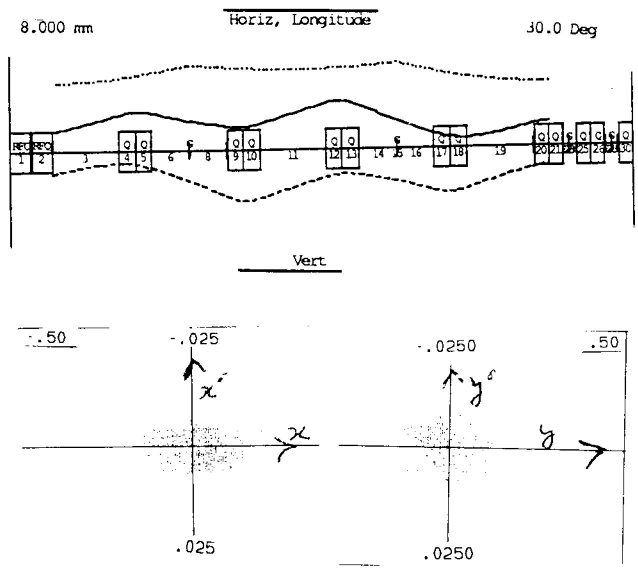

Fig. 3 The rms beam envelope through the matching section . The beam phase space corresponds to the end of the matching section.

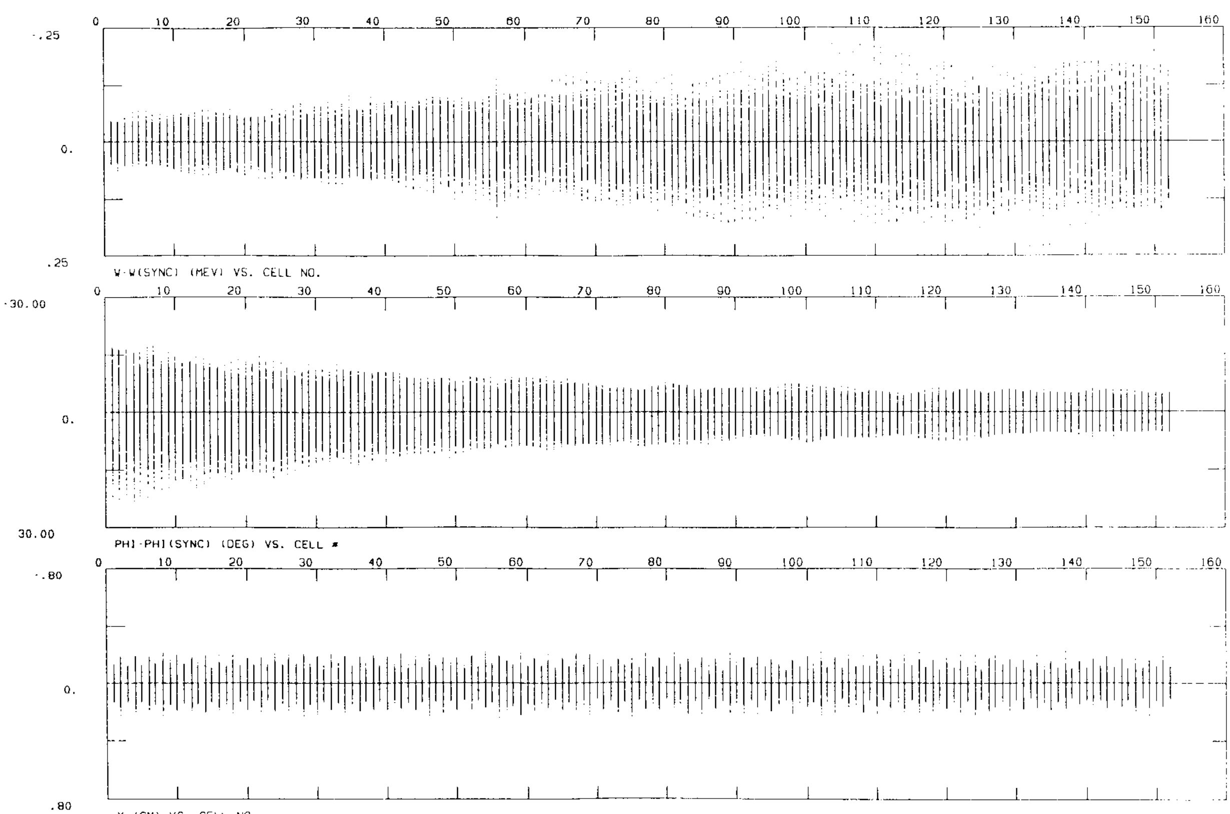

Fig. 4 The beam envelope in x plane, the energy spread and the phase width variation as a function of cell no. in the DTL.

chosen as the final design for the matching section. Fig. 3 shows the matched TRACE 3D envelope for this beam and phase space at the end of the matching section. Fig. 4 shows the beam behavior right up to the end of the DTL. In Fig. 5 is shown the beam phase space in the two transverse planes at the end of the DTL. These are computed by using PARMILA. The particle distribution at the input of the matching section is generated through PARMTEQ [5].

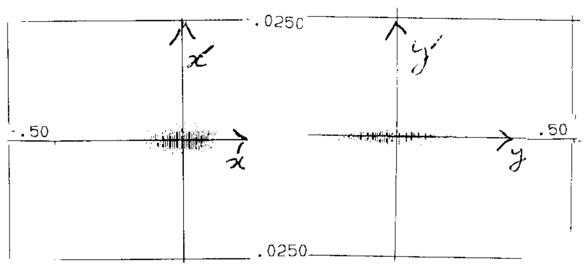

Fig. 5 Phase spaces in the transverse planes, at the end of the DTL.

The design has been checked for beams having characteristics quite different from those of the nominal beam and gives satisfactory results. For a 50 mA, 0.2 mm.mrad beam, the emittance growth at the end of the DTL is estimated as 7.7%. whereas for 30 mA, 0.1 mm.mrad, the growth is 12%. The system can also handle beams having twice the emittance of nominal beam. In this case the beam envelope is about 1.5 times larger but exhibits a very low emittance growth of 0.7%. A variation of about ± 40% in the input Twiss parameters can also be accomodated by this design with no adverse effect on the emittance. Even beams having approximately ten times the phase space density of the nominal beam can also be tackled and matched perfectly but will have an emittance growth of about 45%, at the end of the DTL.

Error Analysis

The effect of positional errors of quads and cavities, the errors in quad gradients, cavity voltage and phase etc. have been analysed in detail. To maintain the emittance growth within the tolerable level of 5%, it looks quite essential to maintain the accuracy in positioning of the quads in the transverse planes to ± 0.1 mm and ± 1 degree. The gradient should be held within ±0.5% of the designed value. The positional errors in the case of the cavities are not as severe as in quads. An error of about ± 1 mm and tilt and yaw of about 2 degrees can be tolerated. However, voltage and phase of the cavity should be held within ± 0.5% and ± 1 degrees respectively.

Beam Steering/Beam Alignment

In this case, the aim was to position the pencil beam anywhere inside the acceptance ellipse of the first DTL magnet, which is estimated approximately as 8 mm by 30 mrad. The scheme employed here uses the horizontal focussing quads for steering in the horizontal plane whereas the vertical focussing quads do the same job in the vertical plane. For a displacement of ± 2 mm, the beam can be steered anywhere inside the acceptance ellipse. This scheme has the advantage that the steering actions in the two planes are decoupled. This is a desirable feature and should serve as a good tool in tuning and aligning the beam.

Fig. 6 shows the mechanical layout of this section, which is in the process of being finalised. The system consists of four variable field permanent magnet quads (VFPMQ) and two double gap buncher cavities, spaced as per the design detail of set no. 5 in Table 1. To get the full information of the beam, various diagnostic devices like beam position monitors, toroids, emittance measurement gear, wire scanner etc. are positioned at various locations.

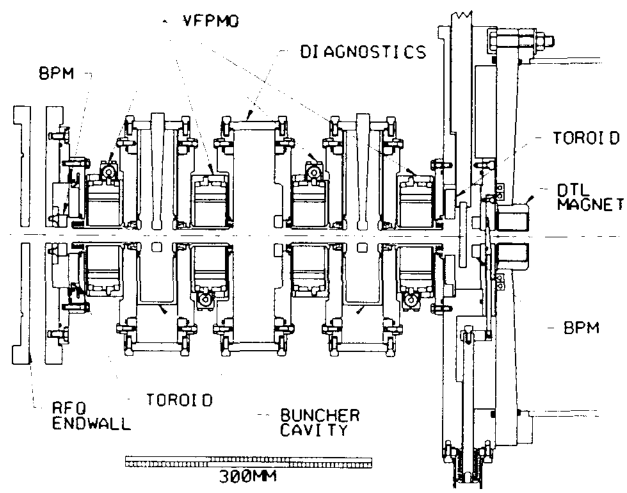

Fig. 6 The mechanical layout of the matching section

Conclusions

The design meets the matching requirements for the beams expected from the system. Emittance growth for the nominal beam is within 5%. The beam can be aligned and steered anywhere within the acceptance area of the DTL.

Acknowledgement

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