SINGLE FREQUENCY HIGH INTENSITY HIGH ENERGY NORMAL CONDUCTING HADRON LINAC*

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Abstract

Considering both the beam quality and the possibility of practical realization, the scheme and parameters for 400 MeV H- linac are discussed. The concepts for beam emittance preservation, both transverse and longitudinal, starting from RFQ, following with PMQ focusing DTL and finishing with high energy CCL part are realized. Several focusing schemes are analyzed for DTL and CCL parts. The pulse beam current is limited to the safe value 40 mA and the average current up to 2 mA is supposed by Duty Factor (DF) of 5%. The operating frequency 352 MHz for all linac parts provides the full unification for RF system of the whole. Expected beam parameters are summarized.

INTRODUCTION

From the beam dynamics issue the smooth continuous acceleration with the minimal number of simple transitions between linac parts is the best case. There is no accelerating structure for effective H- ions acceleration in the total energy range from ~100 keV to ~ 400 MeV and different structures are used in different linac parts, operating at different frequencies. The matching of longitudinal motion is rather complicated. matching for transverse motion is still required. It can be strongly simplified [1] for the single operating frequency f_0 in the whole linac. The scheme of proposed linac includes well known structures. RFQ is an inevitable part in the linac front end and Coupled Cell Linac (CCL) is mostly effective for high energy part. The mostly developed and effective structure for intermediate part is the Drift Tube Linac (DTL). The recent progress demonstrates both RFQ operating f_0~(300-400) MHz and developed CCL for the same frequency range. CERN Linac4 realizes single frequency concept up to H- energy 160 MeV. Below parameters of such linac are estimated for higher output energy. Much more details of this consideration are given in [2]. All simulations for beam dynamics are performed by using LIDOS and TRANSIT codes [3].

LINAC FRONT END

For high power high energy linac the problem of particle losses is of primary importance. The care for emittance growth preservation should be paid starting from ion source and low energy beam transport to RFQ. For RFQ essential parameters are the transverse emittance growth and output longitudinal emittance. The output beam should be bunched without tails in the phase space, which will be transformed further in the beam halo.

To have the initial beam formation, RFQ with f_0=352,2 MHz and output energy W_1=3.0 MeV was estimated [2] assuming voltage 95.0 kV and the maximal electric field E_{smax}=1.85 E_k with the cavity length 3.65 m. For the beam current I_b=40 mA simulations shows transverse emittance growth ~10% and total longitudinal emittance as 0.914 π MeV·deg. For output beam the phase space portraits are shown in Fig. 1. Comparison with the recently achieved results for the J-PARC RFQ, f_0=324 MHz [4], and for SNS RFQ f_0=402.5 MHz, [5] shows the accepted parameters as reliable and RFQ cavity construction for DF=5% as realistic.

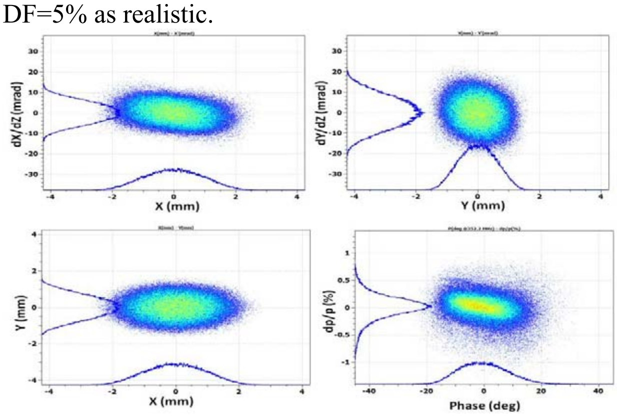

Figure 1: The phase space distributions of particles at the RFQ exit.

MEBT1

The transport line MEBT1 has the length ~2.31 m and is required for matching between RFQ and DTL, placement of chopper and beam diagnostic hardware. The line consists from eleven quads, chopper and beam absorber. To reduce the bunch lengthening along axis, line is equipped with two bunching cavities. The design parameters for MEBT1 elements are quite conservative [2]. Simulations show the transverse emittance growth as ~30% and longitudinal one as ~6%. It id in good coincidence with similar parameters in the existing linacs – SNS, J-PARC and Linac4. The phase space portraits for beam at the MEBT1 exit are shown in Fig. 2.

DTL PART

For DTL with f_0=352,2 MHz application of Permanent Magnet Quads (PMQ) is motivated by higher RF efficiency. RF parameters of DTL cells were studied [2] in the wide range of dimensions. To provide the higher RF efficiency and the safe E_{smax} value <1.3 E_k, one should start with small aperture diameter 2a and drift tube cone angle θ in the DTL beginning and increase it to the DTL

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end. The accepted configuration of DTL cells are shown in Fig. 3 for the middle cells in each DTL tank.

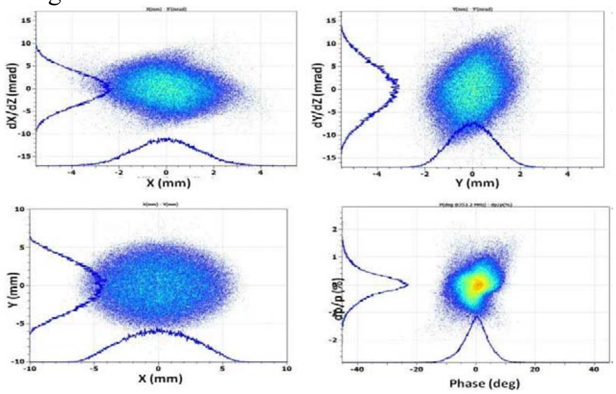

Figure 2: The phase space distributions of particles at the MEBT1 exit.

Two competitive focusing lattices were studied finally – FFDD and FHDH, where H means the empty drift tube without PMQ. Both these schemes have similar total sensitivity to PMQ misalignments and provide similar size for beam envelope. FFDD scheme requires lower focusing gradient and is more easy for beam dynamics understanding. This scheme is realized in Linac 4 for DTL. FHDH scheme requires higher, but realistic gradient, and has twice less PMQs. This scheme has very attractive advantages for the linac technology. In empty tubes correctors and BPMs, similar to SNS DTL, can be placed, improving DTL flexibility for beam transport. Inter tanks space could be arranged more simply. But simulations show indications for some local degradation in the transverse stability in the energy range (3-10) MeV. Particles cross this range fast and without significant deterioration for beam quality, but this point requires additional study. Currently we base on FFDD scheme.

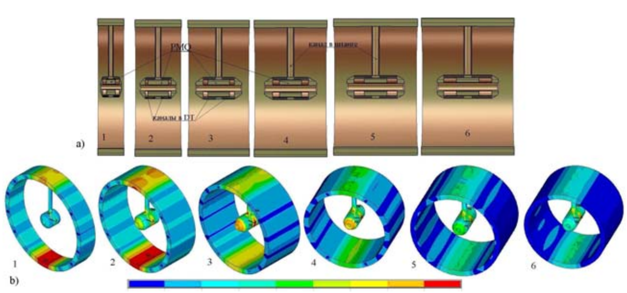

Figure 3: The DTL cells with PMQ in drift tubes (a) and the temperature distribution at the surface for accelerating rate 2.0 MV/m, DF=6% (b).

The PMQ length is accepted as ~40 mm for the first DTL tank and as ~90 mm for all following tanks. The diameter of drift tubes is 90 mm for all tanks. The DTL part consists of six tanks and accelerating rate is ~ 2 MeV/m is accepted preliminary, from costs estimation for accelerating structure and RF sources. The length of tanks L is limited either by 10λ from field stability reasons, or by RF power P_t~2.1 MW at the tank RF window. Conservative value E_{smax} <1.22 E_k is realized by drift tubes shape optimization without significant reduction in the shunt impedance value Z_e. Main parameters for DTL tanks are summarized in the Table 1. Due to similar purposes and assumptions, very similar parameters are independently chosen for ESS DTL, [5]. The technology of construction both for DTL tanks and drift tubes with PMQ, for example, is described in [6].

Table 1: The main parameters of DTL tanks.

	W_{out}, MeV	N_{dt}	2a, mm	ϕ_s, deg	P_{cu}, MW	P_t, MW	L, m
DTL1	18.18	65	20	-30	0.95	1.54	7.399
DTL2	35.86	45	22	-30	0.98	1.67	8.613
DTL3	53.47	35	24	-25	1.08	1.76	8.535
DTL4	71.12	30	26	-25	1.27	1.95	8.513
DTL5	88.23	26	28	-25	1.45	2.11	8.208
DTL6	102.98	22	30	-25	1.54	2.13	7.490

The beam envelope growth along DTL is ~ 40% and the maximal beam radius 5.3 mm is at DTL exit, providing very good aperture/(beam size) ratio, preventing particles losses from beam halo, formatted due to space charge forces together with hardware and tuning errors. At the DTL exit transverse particle distributions are shown in Fig. 4 and transverse emittance growth along DTL is ~ 10%, according simulations. In longitudinal direction we have well formed bunch with the total phase length ~ 15 degree and momentum spread ~0.6%.

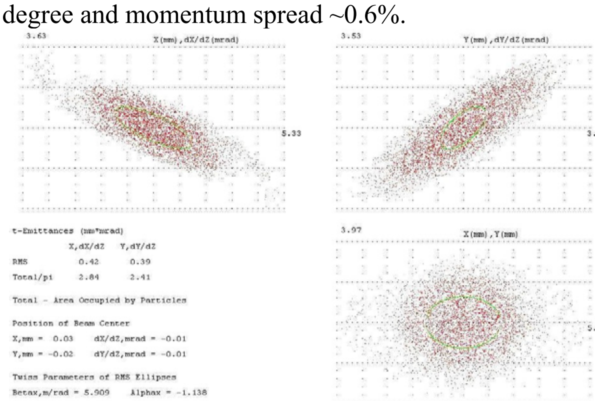

Figure 4: The transverse distributions of particles at the DTL exit.

With PMQ application, DTL RF efficiency in energy range ~80 MeV is high enough and there are no cost effective reasons to develop and introduce additional accelerating structure between DTL and CCL. Transition energy to the CCL part is ~ 103 MeV.

MEBT2 AND CCL PART

At transition energy ~ 103 MeV the beam lengthening is negligible at the length 3.04 m and MEBT2 contains just four EMQ with conservative gradients and beam diagnostic hardware.

For f_0=352.2 MHz CCL structures have much more weak Z_e dependence on aperture radius a (in mm), as compared to CCL at f_0~900 MHz. Comparing FODO, FDO and FDFO focusing with EMQ, we have selected FDO scheme to provide, together with CCL aperture ~ 40

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mm, the higher transverse acceptance with realistic focusing gradient ~30 T/m. Due to operating frequency CCL longitudinal acceptance is large by definition.

For f_0=352,2 MHz application CCL must have reasonable transverse dimension and just two structures look now acceptable – PiMS, realized in CERN Linac 4 [7], Fig. 5a and CDS, Fig. 5b, developed in INR. CDS has higher Z_e value and the qualitative advantage in field stability, looks more labour-intensive in construction, but it is easy in RF tuning. Detailed PiMS and CDS comparison is in [8,2].

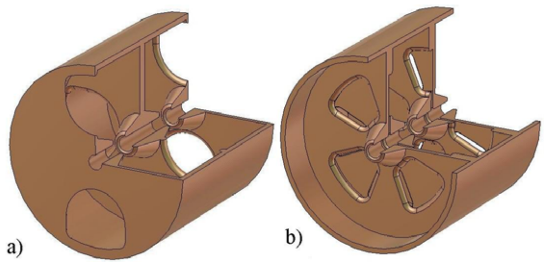

Figure 5: Accelerating structures, acceptable for f_0=352,2 MHz, PiMS (a) and CDS (b).

CCL part has the high canal acceptance and different options are considered, [2]. With RF power dividing one klystron feds two or four CCL tanks, forming together RF unit. For accelerating rate ~2 MeV/m the total number of CCL cells in one RF unit is ~30. To reduce cost, all CCL cells inside one RF unit are identical. Tanks are placed so, that reference particle cross the tanks centres at the prescribed phase ϕ_s. By fitting a geometrical β of cells in the unit, the maximal phase slip over tanks is minimized. We use actively both large CCL acceptance and small phase length of the bunch. For further cost reduction due to RF system simplification, the unit with two tanks, containing 15 CCL cells each, is studied in more details and beam envelopes along CCL part are shown in Fig.6.

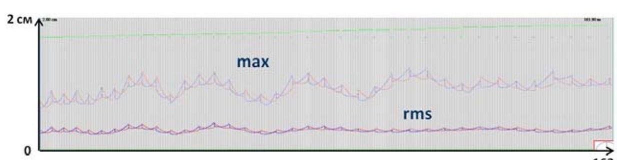

Figure 6: The beam envelope in CCL.

The transverse emittance growth along CCL is ~40% and longitudinal one – at 2.5%. The CCL part consists of 18 RF units and the total linac length this case is ~ 221 m.

RF SOURCES

The most appropriate RF source for designed linac is the klystron TH2179, [10], accepted also for CERN Linac 4. With the combination of pulse RF power 2.8 MW and average power 210 kW is allows operation with DF =7.5% and high efficiency 55%. Having the designed RF pulse length τ=1.5 ms, this klystron was tested for ESS DTL with τ>2.3 ms. Another required RF hardware, listed in [2], is already developed and tested in CERN Linac 4.

BEAM POWER

In present hadron linacs I_b is restricted with safe and realistic value ~(40-50) mA. Required beam power is by DF increasing. With high heat load for structure, the special care should be to thermal deformations. For DTL and CCL cells thermal effects were studied, [2,8], for DF=6% operation. The temperature distributions for DTL cells are shown in Fig. 3b. The operating frequency shift ~-60 kHz will be compensated by fast movable tuners in DTL and CCL tanks. It is more fast and precise method to control frequency for high heat load, when cooling water just remove heat from cavity. Operation with DF=5% is not unique. Operating SNS linac has DF=6%. For J-PARC linac, operating now with DF=3%, structures are designed to withstand with DF=15%, and for CERN Linac4 – with DF=10%.

CONCLUSION

The single frequency solution for the high power high energy hadron linac results in the comfortable conditions for beam dynamics with sufficient reserve. High beam quality allows optimal solutions and safe regimes for hardware operation. Unified RF system is cost effective in design, construction and maintenance. Required parameters for all linac parts are confirmed in the world wide practice. It is promising and cost effective direction for development and construction of such type normal conducting linacs.

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