POST-ACCELERATOR LINAC DEVELOPMENT FOR THE RIB FACILITY PROJECT AT VECC, KOLKATA

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Abstract

An ISOL (Isotope Separator On Line) type of RIB (Rare Ion Beam) facility is being developed at our centre. The post-acceleration scheme will consist of a Radio Frequency Quadrupole (RFQ) followed by a few IH LINAC cavities - further augumentation of energy using SC QWRs will be taken up at a later stage.

The first two IH cavities have been designed for 37.6 MHz frequency like the preceding RFQ to keep the RF defocusing smaller. Explosively bonded copper on steel has been used for the fabrication of the IH cavities and the inner components have been from of ETP grade (UNS C11000) copper. Also, we have adopted an octagonal cross-section for the cavity structure to avoid fabrication complicacies. The first and second cavity have inside lengths of 0.62 and 0.97 m respectively and the inside separation between two opposite sides of the octagon is 1.72 m.

Thermal analysis of the cavities has been carried out and cooling configurations have been optimized accordingly to control the temperature rise of the LINACs. Detailed mechanical analysis has been carried out to reduce the deflection of the LINAC components under various loads.

Design and fabrication aspects of these two cavities and results of the low power tests will be reported in this paper.

INTRODUCTION

Rare Ion Beams (ions of β-unstable nuclei) offer many new possibilities in different branches of accelerator based research. An ISOL type of RIB facility is being developed at our centre [1]. Light ion beams (p, α) from the K=130 cyclotron will be used as a primary beam for this facility. Also an electron LINAC is being developed at present which will open up the possibility of producing RIBs using photofission route. The primary reaction products will be ionised using an on line ion source and mass separated to choose the RIB of interest from the other reaction products. The RIBs will be accelerated from 1-97.5 keV/u using a heavy ion RFQ [2, 3, 4] operating at 37.6 MHz. Further acceleration up to 1.2 MeV/u will be done using IH LINAC cavities. The first two of these cavities have been designed and fabricated. Low power tests have also been performed. Design and fabrication aspects of these two cavities and results of the low power tests will be reported in this paper.

DESIGN REQUIREMENTS

The initial energy of the RIBs after the mass selection is 1.7 keV/u. The RIBs will be accelerated in stages - the first post-accelerator is a RFQ which accelerates up to about 98.7 keV/u at 37.6 MHz, followed by two IH cavities at the same frequency to reach 287 keV/u - all of them are designed for $q/A \geq 1/14$. This will be followed by one IH cavity designed for 75.2 MHz to reach 409.1 keV/u. There will be a charge stripper at this stage and this will be followed by three more IH cavities designed for $q/A \geq 1/7$ to reach around 1.2 MeV/u. Further acceleration using QWRs are being planned at present.

The intensity of RIBs is a prime concern as it is significantly lower than stable ion beams in most of the cases. So, the LINACs have been designed for high transmission efficiency of the ions. Many experiments require measurement of parameters at various energies and therefore the aim is to continuously vary the energy of the beam without significant loss of intensity or degradation of beam quality (spot size and energy width).

DESIGN PRINCIPLE

The acceleration method adopted in our design consists of classical negative synchronous phase small length LINACs with transverse focusing quadrupole triplets in between the cavities. Buncher cavities will also be accomodated where need arises. The cell parameters of the LINACs have been calculated by tracking trajectory of an ion having designed values of phase and velocity by integrating its equation of motion using static electric field obtained from *POISSON* code for a particular drift tube geometry – ignoring the details of the drift tube supports, ridges and cavity. With this drift tube (DT) and gap geometry, the cavity parameters have been optimised using *ANSYS*. The detailed beam dynamics have been studied using interpolated field from *ANSYS* using *VECLIN* code. Details of this design principle has been reported elsewhere [5].

The important parameters for the first two IH cavities are shown in Table 1. The frequency of first two LINACs has been kept same as that of RFQ to keep the RF defocusing smaller for low input energy. The shunt impedance and Q-values of the table are *ANSYS* results and the power has been calculated for a 60% shunt impedance value. The beam energy can be veried without any significant loss of intensity or degradation of beam quality. Fig. 1 shows two possible tunes for 286.8 keV/u energy - the case for good transmission (top) and good beam quality (bottom). This has of course still room for improvement by reducing the inter-tank separation.

Table 1: Important parameters of frst two IH cavities

Parameter	Unit	LINAC-1	LINAC-2
Frequency	MHz	37.6	37.6
q/A		$\geq 1/14$	$\geq 1/14$
$T_{in}(\beta_{in})$	keV/u	98.8(1.46)	183.6(1.98)
$T_{out}(\beta_{out})$	%	183.6(1.98)	286.8(2.48)
Gaps		9	10
DT ID	mm	25	25
DT OD	mm	69.5	60
Gap length	mm	29.2	39.8
Peak potential	kV	101.24	107.5
Max. field	E_{Kil}	1.4	1.3
Sync. phase		-24°	-25°
Cavity length	m	0.618	0.871
Accln. gradient	MV/m	2.102	1.79
Shunt impedance	MΩ/m	342	432
Q-value		13765	18963
RF power	kW	19.9	16.4

Mechanical Aspects

The two cavities have been fabricated using explosively bonded copper (grade ETP or UNS C11000) on steel (grade SS304L or UNS S30403). Also, bending of copper bonded with steel has been avoided using an octagonal cross-section of the cavity. Each of the ridges and drift tubes have been fabricated from single block of ETP grade copper.

The thermal load on the cavity has been calculated from RF analysis and used for the optimisation of cooling channels of the LINACs using adequate safety factor. A typical example of such analysis is shown in Fig. 2. In the worst case scenario, there may be a temperature rise of about 15°C at some locations within the cavity. The LINACs are subjected to loads due to atmospheric pressure, gravity and temperature distribution. The deformations may affect the alignment of the drift tubes and the end gaps of the LINACs. The thickness of the materials of the cavity and the end covers have been optimised to reduce this effect. In addition, circular reinforcements have been incorporated on the end covers and optimised to further minimise this effect. A typical simulation is shown in Fig. 3.

FABRICATION & ALIGNMENT

The cavity has been fabricated by full penetration TIG welding of the steel plates by removing copper close to the welding joints. Adequate precautions have been taken to minimise the distortion during welding. After the fabrication, the faces of octagon on which ridges are supported have been machined to get the desired flatness, parallelism and equal distance from the centerline. Entire final machining job of the cavity with end plates have been done in a single setting of CNC machine. All inner components have also been machined using CNC. After the machining, the drift tubes were placed and their center line deviations were measured using optical theodolite with proper target fixtures. The final machining of drift tube bases were done based on the initial measurement data. The drift tubes could be aligned within an accuracy of 150 μm and the drift tube gaps have been maintained within $\pm$50 μm. Fig. 4 shows the LINAC-1 during final assembly.

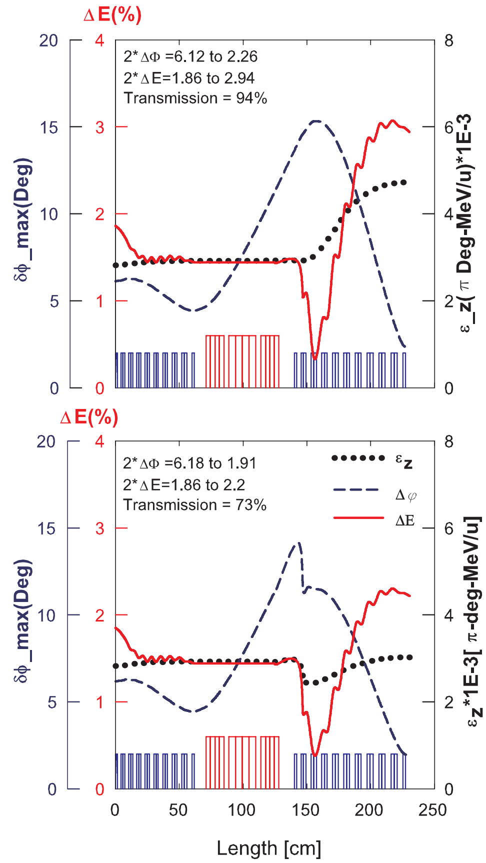

Figure 1: A typical tune through two LINAC cavities showing the variation of rms energy width, phase width and longitudinal emittance growth.

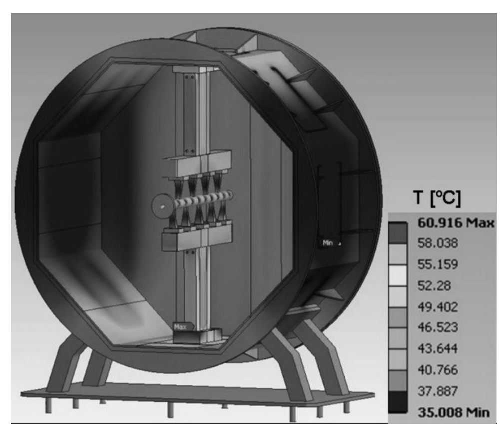

Figure 2: Temperature profile of LINAC-2 calculated using ANSYS.

Both LINAC-1 and LINAC-2 have passed the vacuum

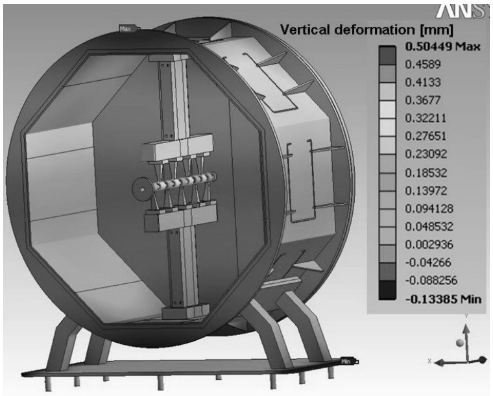

Figure 3: Structural deformation of LINAC-2 calculated using ANSYS.

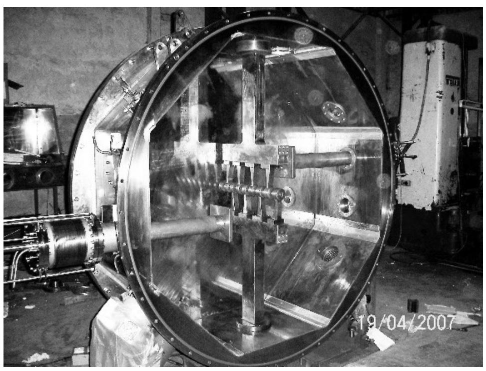

Figure 4: LINAC-1 during assembly.

performance test. Each of the LINACs with their inner components have been leak tested and no local leak could be traced up to a level of 1E-9 mbar-LPS. Both of them have been pumped using two 500 LPS turbo drag pumps after initial pumping using dry pumps. LINAC-1 reached a vacuum of 1.4E-6 mbar after about 1 week of pumping after the final cleaning. LINAC-2 reached a vacuum of 2.7E-6 mbar after about 24 Hours of pumping at manufacturer's site before the final cleaning. The performance is likely to improve significantly after the RF conditioning.

LOW POWER TEST

Both LINAC-1 and 2 were initially assembled at manufacturers site and RF measurements were done. LINAC-1 has been throughly cleaned in our site and assembled again and RF tests have been repeated again and it is ready for putting into operation. Results of these measurements are shown in Table 2. The frequency measurements are within 0.3% of the calculated values. The measured Q_0 values for LINAC-1 and 2 are 59% and 35% of the calculated values. A significantly lower value of Q_0 for LINAC-2 is due to the facts that many of its inner components were not having the required surface finish at the time of testing and also no RF springs were used during testing. The Q_0 value has significantly increased to 71% of the calculated value when LINAC-1 has been assembled after through cleaning and putting RF contact at all joints. We expect similar result for LINAC-2 also.

Table 2: Important parameters of frst two IH cavities

LINAC	**Freq. [MHz]**		**Q_0-value**	
Number	**Calc.**	**Meas.**	**Calc.**	**Meas.**
1	37.695	37.75	13765	8073
2	37.861	37.75	18963	6687

The electric field on the axis of LINAC-1 has been measured using bead perturbation technique. In which a dielectric bead was made to move along the drift tube axis in small steps and the frquency deviation was calculated using network analyser. Results of this measurement is shown in Fig. 5 where the *ANSYS* calculated field is also shown.

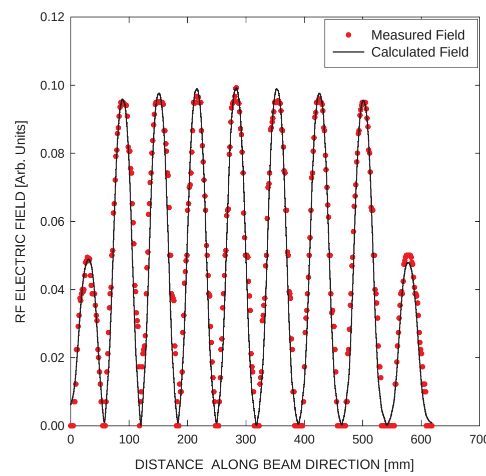

Figure 5: Results of bead perturbation measurement of LINAC-1.

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