DESIGN OF RE-BUNCHER CAVITY FOR HEAVY-ION LINAC IN IMP

L. Sun#, Y. He, A. Shi, X. Du, Z. Zhang, C. Zhang
Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China

Abstract

A re-buncher with spiral arms for a heavy ion linear accelerator named as SSC-LNAC at HIRFL (the heavy ion research facility of Lanzhou) has been constructed. The re-buncher, which is used for beam longitudinal modulation and match between the RFQ and DTL, is designed to be operated in continuous wave (CW) mode at the Medium-Energy Beam-Transport (MEBT) line to maintain the beam intensity and quality.

Because of the longitudinal space limitation, the re-buncher has to be very compact and will be built with four gaps. We determined the key parameters of the re-buncher cavity from the simulations using Microwave Studio software, such as the resonant frequency, the quality factor Q and the shunt impedance. The detailed design of a 53.667 MHz spiral cavity and measurement results of its prototype will be presented.

INTRODUCTION

The spiral cavity shown in Fig.1 is a kind of characteristic RF structure other than QWR (Quarter Wave Resonator) cavity, whose remarkable properties are attributed to a high efficiency, compact design and a big variety of possible fields. In comparison to other available designs, the advantage of this structure lies in its small size. Furthermore it can easily be tuned to expected frequency point by varying the length of the spiral. Of course, due to the small size the required budget can also be kept low. This re-buncher resonator, having four gaps in it, operates at a fixed frequency of 53.667MHz to provide the longitudinal focusing of 7.12MeV heavy ion beam. To reduce the risk of sparking, the voltage of gaps is well optimized at 30kV. The bunching voltage, which is defined as the sum of the four gap voltages, has reached 120kV at a power consumption of 0.95kW.

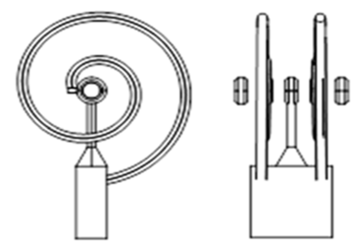

Figure 1: Schematic drawing

DYNAMICS DESIGN

According to the design for LINAC [1] which are presented in Fig.2, the re-buncher is located between the RFQ and the IH-DTL cavities, and it can be used to provide adjustable longitudinal focusing force to guarantee that most particles do not exceed the longitudinal acceptance of the DTL. The longitudinal emittance of the main bunch and the longitudinal acceptance of the DTL at its entrance are illustrated in Fig.3. The void region is the longitudinal acceptance of the whole DTL. The area occupied by black dots is the matched longitudinal particle distribution at the entrance of the DTL. Obviously, without bunching function, the majority of particles will lost, only 23.2% particles can be accelerated by the DTL. When the re-buncher is turned on, a satisfying result can be acquired by optimizing the re-buncher structure and its bunching voltages

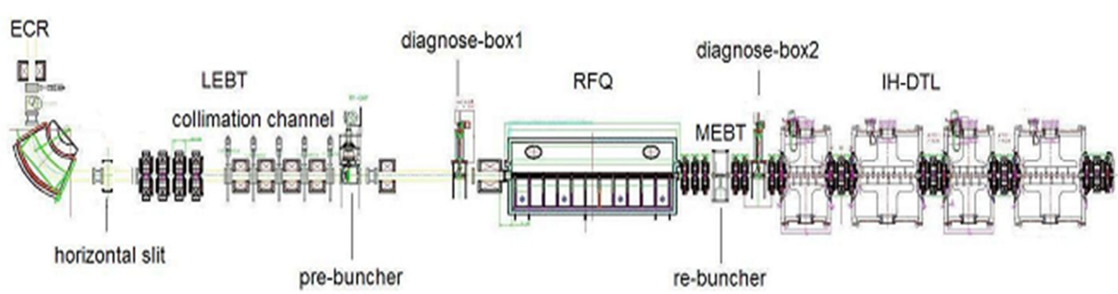

Figure 2: The layout of the SSC-LINAC

sunlp@impcas.ac.cn

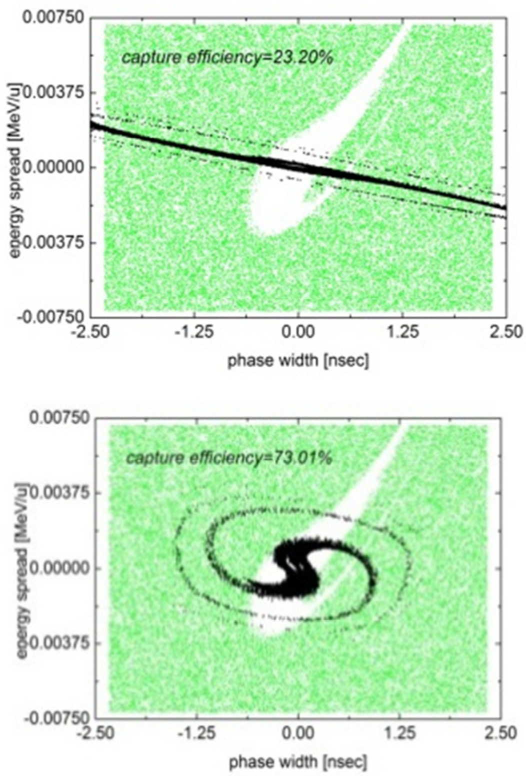

Figure 3: The particle longitudinal distribution when the re-buncher turned on (bottom) and off (top) respectively.

MAIN PARAMETERS

According to the specification of re-buncher shown in Fig.4 and Tab.1, the sizes of all parts need to be confirmed to meet the requirement of the accelerators' conditioning. The dimension of the resonator is coming from the process of EM optimization and mechanical consideration. With the repeated parameters' sweep, the size of every part has already obtained.

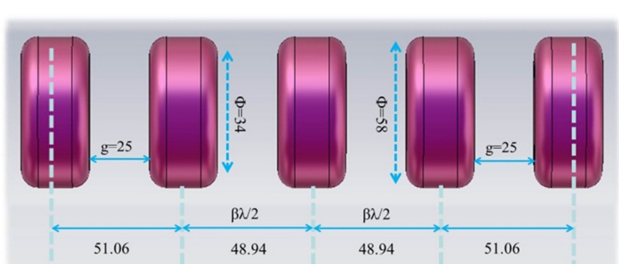

Figure 4: The dimension of drift tubes.

Table 1: The parameters of dynamics design

specification	value	unit
resonant frequency, f	53.667	MHz
velocity, β	0.0175	
charge to mass ratio	1/7	
operating energy	0.143	MeV/u
accelerating voltage, V	30	kV/gap
length of cavity, βλ	22.9	cm
tank diameter	60	cm
diameter of aperture	3.4	cm
voltage stability	±1%	
phase stability	±0.3%	
vibration amplitude	±0.1	mm
operating mode	CW	

SIMULATION RESULTS

The main results of the dynamics simulation for the complicated multi-gap resonator using RF design software named Microwave Studio are presented in Tab.2.

Table 2: The simulated results

characteristic parameters	results	unit
resonant frequency	53.7676	MHz
total energy	1	joule
total power loss	83.04	kW
shunt impedance	2248	kΩ
gap voltage	227.38	kV
R/Q	153.044	Ω
Q-factor	4068.2	

The main consideration for cooling is to analyze the surface current distribution [2] which is indispensable to the structural and thermal designs. Another concern is the voltage distribution along z-axis.

POWER SIMULATION

The power consumption of the cavity can be estimated easily from the above calculated results. First of all, the shunt impedance of four gaps R (about 2248 kΩ) is a key factor. According to the simulated results and the design voltage of each accelerating gap, the magnitude of total power consumption of the cavity can be estimated roughly by using formula as follow:

$$P= (16V_{gap}^2/2R) = 0.95 \text{ kW}$$

We can also estimate the cavity power loss which usually accounts for the power margin, thus a 2 kW amplifier is needed.

COUPLING LOOP [4]

The RF power will be fed into this cavity by a coupling loop which is located near the root of the spiral. The loop area of 100 cm^2 will provide impedance matching of 50

ISBN 978-3-95450-122-9

ohms. Now this coupler has been designed and simulated at IMP.

PROTOTYPE CAVITY

By May 2011 the prototype cavity has already been manufactured at IMP. The structures are shown in Fig.4.

Considering the cavity cost, we decided to choose the carburizing steel for the outer housing and the aluminum for the inner conductor. The measurement results are shown in Tab.3 and Fig.5:

Table 3: Measurement results

characteristic parameters	measured results	unit
resonant frequency	53.678	MHz
scattering parameter(S_{11})	-24	dB
tuning range	±152	kHz
R/Q	142.5	Ω
Q-factor	702	
flatness of Electric field	≤2.65%	

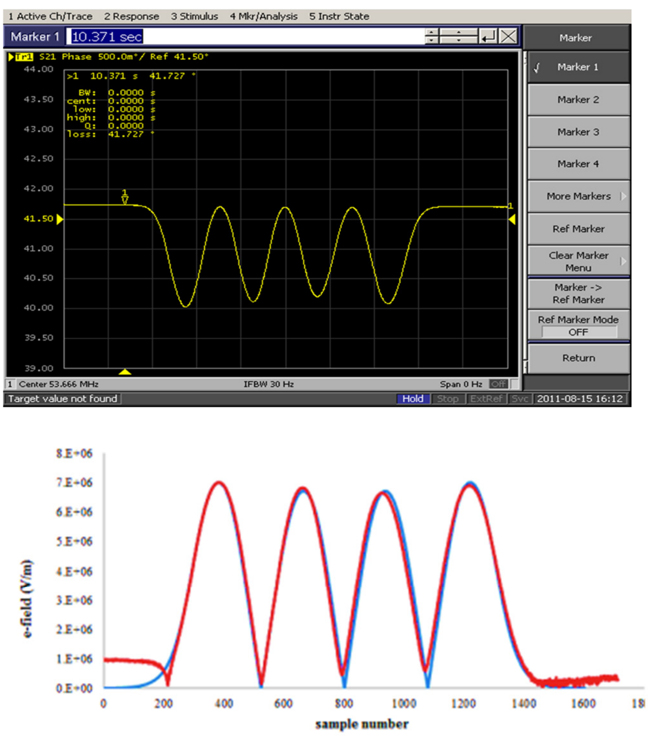

Figure 5: Measurements and analysis of the electric field flatness, the top figure shows the measured results of the phase shift and the bottom figure is the comparison between the simulated results (blue line) and the measured results (red line).

SUMMARY

From the measured Q value as above, we found that the material conductivity could be the primary problem. Through the analyzing the power loss in the lossy resonator presented in Fig.6, the spiral arms and wall are realized to consume the majority of the RF power. And the materials of the prototype are the carburizing steel and duralumin with low conductivity. Using these materials, the simulated Q-factor is no more than 1200. According to the simulations and measurements, we think that a copper spiral cavity will improve its performance greatly, especially for the Q value and shunt impedance. Of course, a good contact and careful assembly are not to be neglected.

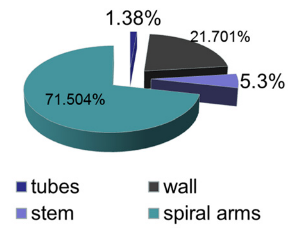

Figure 6: the power distribution

The re-buncher at the MEBT is very important for the longitudinal matching between the DTL and the RFQ cavity. The RF performance of the cavity with two spiral arms has been simulated. Now a full-scale prototype has already been manufactured. The primary measurement shows that the re-buncher design can meet the requirements of the linear accelerator. Although the Q factor is only 702, a little far away from the original design, this value agrees well with the calculated value of the lossy metallic material. In addition, the trajectory tracking results based on the electromagnetic simulation have been finished to help understand the dynamics process.

Now further study of various properties for this cavity is in progress, including all the basic tests using vector network analyzer and the bead-pull measurement [5].Then, a lot of work still need to be done, including fabricating a solid-state amplifier and developing a real copper cavity.

REFERENCES

[1] Xiao Chen, He Yuan, Yuan Youjin, et al. Particle-in-cell mode beam dynamics simulation of the low energy beam transport for the SSC-linac injector, Chinese Physics C, 2011,35(5):500-504.

[2] Schuh M, Kuhnel K U, Welsch C P, Optimization of spiral-load cavities using the 3D code opera/soprano[C]. Proceedings of LINAC, 2008.

[3] Mitra A K, Poirier R L, A 35MHz spiral re-buncher cavity for the TRIUMF ISAC facility[C]. Proceedings of 1999 particle conference, 1999.

[4] Welsch C P, Kunel K U, Schempp A, Development of rebunching cavities at IAP[C]. Proceeding of LINAC2000, 2000.

[5] Mitra A K, Poirier R L, High power test of the 35 MHz spiral re-buncher cavity for the TRIUMF ISAC Facility[C],1999.