COMMISSIONING OF SUPERCONDUCTING LINAC AT IUAC – INITIAL CHALLENGES AND SOLUTIONS

S.Ghosh, R.Mehta, G.K.Chowdhury, A.Rai, P.Patra, B.K.Sahu, A.Pandey, D.S.Mathuria, J.Chacko, A.Chowdhury, S.Kar, S.Babu, M.Kumar, R.S.Meena, S.S.K.Sonti, K.K.Mistry, J. Zacharias, P.N.Prakash, T.S.Datta, A. Mandal, D.Kanjilal and A.Roy, Inter University Accelerator Center, Aruna Asaf Ali Marg, New Delhi - 110067

Abstract

During initial operation of the first linac module, energy gain was found to be much lower due to various problems which are now identified and solved. A novel way of damping mechanical vibration was implemented to reduce RF power. Cooling was improved by installing a hemispherical structure on the resonator. The drive coupler was redesigned to eliminate metal coating. Design of the tuner/transition flange assemblies was modified to avoid cold leak. After incorporation of these modifications, a few on-line beam accelerations through Linac were accomplished. In one of the beam acceleration, pulsed (1.3 ns) Silicon beam of 130 MeV from Pelletron accelerator was further bunched to 250 ps by SC Superbuncher. After acceleration through the linac module and subsequent re-bunching using SC Rebuncher (RB), 158 MeV Silicon beam having pulse width of 400 ps was delivered to conduct experiments.

INTRODUCTION

To augment the energy of the ion beam from the Pelletron of Inter University Accelerator Centre (IUAC), a niobium based superconducting (SC) linac [1,2,3] is under construction. Full linac will consist of five cryostats, the first one is the superbuncher cryostat housing single quarter wave resonator (QWR), the next three cryo-modules house eight QWRs each and the last cryostat has two QWRs to be used as re-buncher/de-buncher (Figure 1).

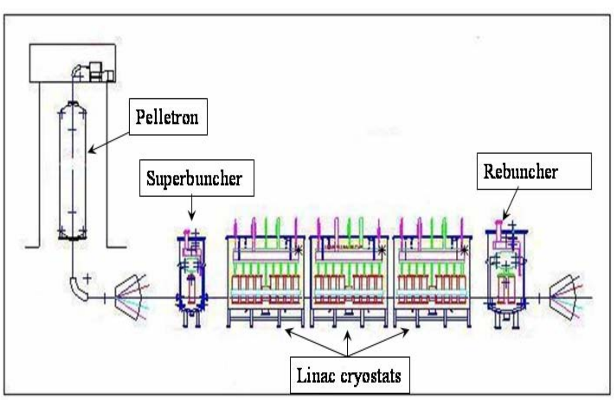

Figure 1. The schematic of the Pelletron and Superconducting Linear accelerator of IUAC

At present, linac line comprises of the superbuncher cryostat followed by a single cryo-module and the rebuncher cryostat. In the past, pulsed silicon beam from the Pelletron had been accelerated through five resonators of the first linac module. However, due to various problems [4], the accelerating field achieved from the resonators were less and therefore the energy gain measured from the acceleration was found to be lower than the designed goal [5]. To address this problem, a few major modifications were carried out successfully. During the recent on-line beam experiments, an accelerated beam from Pelletron and linac was delivered to conduct nuclear physics experiments. The details of the solution of different problems and the results of the on-line tests are presented in this paper.

INITIAL OPERATIONAL PROBLEMS

The problems can be broadly classified into two categories: (a) the degradation of the accelerating field of the resonators in linac cryostat compared to the performance in test cryostat and (b) the lack of ruggedness and reliability of the mechanical tuner of the resonators.

Poor performance of the QWR in linac cryostat

During initial performances tests of superconducting QWRs in linac and test cryostats, it was observed that the accelerating fields of the resonators were lower by a factor of two or more compared to the fields obtained in the test cryostat. This decrease in field was attributed to the inefficient cooling of the top portion of the resonators due to trapping of bubbles in that area.

Due to presence of microphonics in the ambience of cryostat, large amount of over coupling of the power coupler was required with forward power of 150-300 watts from the RF amplifier. This resulted in the power coupler getting heated to a temperature of 150 C or higher. This high temperature probably caused local vacuum deterioration, leading to multipactor discharge resulting in more local heating and subsequent Zinc deposition from the brass material of the rack of the drive coupler [6] inside the resonator. The metal coating on the superconducting surface of the resonator was one of the major reasons for the poor performance of the resonator in linac cryostat.

Reliability problem of the mechanical tuner

During the operations of QWR, slow tuning of the resonators is achieved with the help of a mechanical tuner. The mechanical tuner consists of a niobium bellows, which is located close to the high voltage end of the resonator. By changing the gap between the tuner plate and the high voltage end of the resonator, the frequency is modified up to ± 25 KHz. This gap used to be varied by inserting He-gas inside niobium bellows at a maximum pressure difference of 1.5 bars. During the operation of the resonators in the past, cold leak from the vacuum seal (which isolates He-gas from the cryostat vacuum) and the electron beam joints of the niobium convolutions of the tuner bellows was a constant problem.

MODIFICATIONS TO RECTIFY THE PROBLEMS

Modifications to enhance cooling efficiency

In our old design, at the top of the resonator, there used to be a flat flange (SS) with a 40 mm diameter bellows through which liquid helium enters into the resonator from helium vessel. Just below this flange, about 15 mm down, the resonator's niobium flange, which carries maximum current when the QWR is energised, is located.

To avoid trapping of bubbles at SS flat flange on the top of the resonator, the flat flange was replaced by a hemispherical structure [4]. With these modifications, a number of cold tests were performed on different resonators in linac cryostat and improved electric fields comparable to the results in the test cryostat were obtained.

A novel technique to reduce the forward power during operation

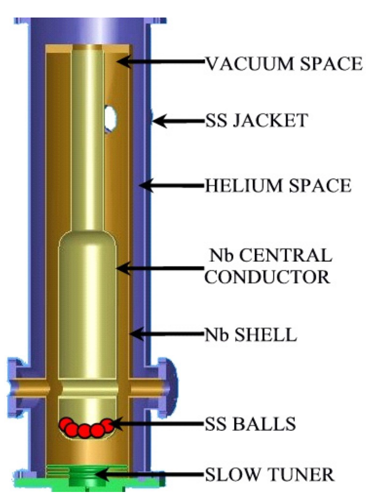

Figure 2. Cross-sectional view of a resonator along with a few SS-balls.

During the operation of QWR in linac cryostat, a typical unloaded Q of ~ 2.0 x 10^8 corresponding to a field of 3-5 MV/m @ 6 watts of RF power loss in the resonator is usually obtained. To achieve a stable operation of the superconducting resonators, dynamical feedback control of amplitude and phase [4] was adopted and a frequency window of ± 50 Hz (Δf) was found necessary for locking the resonators in presence of microphonic noises. To obtain this large bandwidth, resonators were strongly over-coupled corresponding to a reduced Q-value ~ 1 x 10^6 and increased value of coupling coefficient of β ~ 200. At this condition, the power required to lock the resonator is found to be ~ 300 watts. To reduce the forward RF power, ordinary polished stainless steel balls of diameter 4.0 mm were inserted at the end of the helium side of the drift tube [figure 2]. Due to the presence of vibration in the cryostat, the mechanical mode of the resonator (~67 Hz) would be excited. The dominant lowest mode is the vibration of the central conductor with its anti-node at the free end, where the SS-balls are rested. The dynamic friction between the balls and the niobium surface acted to dampen the oscillation reducing the amplitude of the vibration of the mechanical mode substantially. The frequency excursion around the mean frequency of the superconducting resonator with and without SS balls as vibration damper was measured with the help of a device called Cavity Resonance Monitor (CRM) [7]. A reduction of ~ 50% or more in the overall frequency excursion (Δf) and the forward power requirement of the resonator were measured with SS-balls in repeated experiments with different QWRs. During the last off-line performance test in linac cryostat, it was observed that with the new damping mechanism, a forward power of less than 100 watts were found to be adequate for every resonator to lock it at maximum achievable field (3-5 MV/m) at ~ 6 watts of power going into LHe [8]. When the resonators were locked in the past without damping mechanism for maximum achievable fields, larger forward power of factor of 2 or more was required.

Redesigning of the drive coupler

Figure 3. Picture of the drive coupler to feed power

To eliminate any possibility of metal coating on niobium surface during the operation of the resonators in future, three new types of the drive coupler were fabricated. In the most successful design (Figure 3), the rack and pinion made by brass was moved outside the resonator. During several off-line tests of the resonators with these three new drive couplers, no coating was observed on niobium surface or on the inside portion of the drive coupler.

Modifications of the transition flange assembly and the fixture of the mechanical tuner

To join the outer body of the niobium resonator with the outermost SS-jacket, explosively bonded transition flanges made by niobium and SS are used. Edge welded SS bellows are also used to join transition flanges with the SS-jacket to accommodate the differential contraction between niobium and SS at 4.2 K. It was found that after a few thermal cycles, the thin edge welded SS-bellows started leaking in pressurized cold condition and finally they are to be replaced by the thicker formed SS-bellows to solve the problem [5].

The mechanical tuner is a device made by edge welded niobium bellows using 0.7 mm sheets. In our old design, helium gas used to enter inside the niobium bellows directly to flex it and hence a vacuum seal separating the cryostat vacuum from the helium gas was required. This arrangement had created two types of problems. After baking and subsequent cooling of the resonators, the vacuum seal used to leak sometimes. Secondly, small leaks appeared in a few welds of niobium bellows after a number of thermal cycles. To solve these problems, the fixture of the mechanical tuner is modified in such a way that helium gas doesn't reach inside the niobium bellows and consequently, the vacuum seal is no more required. In addition, any weld leak in the niobium bellows won't create any problem as helium gas now flexes another SS-bellow, which pulls or pushes the niobium bellow by a SS-shaft.

BEAM ACCELERATION THROUGH THE FIRST LINAC MODULE

After incorporating all the modifications, a couple of off-line tests followed by on-line beam acceleration had been performed. In both the tests, the performance of the resonators was satisfactory. To measure the energy and time width of the beam, two scattering chambers are placed before and after the linac cryostat. Surface barrier detectors were placed in both the chambers to measure the time and energy of the scattered particles from a thin gold foil. During beam acceleration, $^{28}Si^{+10}$ beam of 130 MeV from Pelletron accelerator was pre-bunched to ~ 1.5 nsec by a multi harmonic buncher and a high energy sweeper located in pre-tandem and post tandem location respectively. With careful optimisation of the phase and amplitude of the resonator acting as a superbuncher, the bunched beam was further compressed to ~ 250 psec at the entrance of linac cryostat.

The beam with 250 ps time width was then injected into the seven resonators of linac cryostat and a total energy gain of about 28 MeV was measured from all the seven resonators of linac cryostat by another thick surface barrier detector (300 μm) at the exit of linac.

The beam was then transported up to the rebuncher (RB), located about 14 meters down the line from the first linac cryostat. By optimizing the reference phase of a single resonator of the RB cryostat and then by changing the amplitude of the accelerating field, the time width of the beam bunch measured at the user's scattering chamber could be compressed from 1.1 ns to ~ 400 ps.

In a subsequent experiment, 100 MeV $^{16}O^{+8}$ beam from Pelletron, pre-bunched by MHB and low energy chopper, to a time width of ~1.0 ns was injected into SB. The resonator in SB had produced a time width of ~160 ps at linac entrance and after acceleration by seven resonators in linac, a total energy of 120 MeV was obtained at the exit of linac. This beam was then re-bunched by a QWR in RB to a time width of ~ 500 ps and was delivered at the experimental chamber to conduct experiments.

CONCLUSION

The pulsed beam from Pelletron was further bunched using superbuncher and accelerated using QWRs in the first cryo-module and then bunched again using the rebuncher successfully after solving the initial problems. Beams accelerated by Pelletron plus linac were delivered for conducting nuclear physics experiments. The designs of the power coupler and slow tuner of the resonators have now been frozen and the same designs are going to be followed for the other two remaining cryostats. The novel method to damp the mechanical vibration of the QWRs by SS-balls and the dome shaped structure are also going to be implemented for QWRs of second and third cryostats.

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