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RECENT PROGRESS OF THE SSC-LINAC RFQ*

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Abstract

The project of SSC-LINAC RFQ has important progresses in the past year. The machine has been moved to the Institute of Modern Physics in the first season of 2013. The cavity measurement including tests of RF performance and field distribution is carried out again in the laboratory. The Q_0 is 6440, and the unflatness of the electric field in longitudinal is ±2.5%. The results demonstrated a good agreement with simulation. The RF and beam commissioning of the RFQ has been carried out in the first half of 2014. The duty factor rose from 5% to CW gradually. By now, the cavity has been operated with 35 kW on CW mode. The measurement of the bremsstrahlung spectrum reveals that the 35 kW power is needed to generate the 70 kV inter-vane voltage. The beam transmission efficiency and energy spread has been obtained in beam commissioning by accelerating $^{16}O^{5+}$ and $^{40}Ar^{8+}$ beams. The efficiency of $^{40}Ar^{8+}$ is as high as 94%, and the output energy is 142.78 keV/u. All the processes and results of the experiments will be discussed in details.

INTRODUCTION

The new linac injector SSC-LINAC [1] has been into the first commissioning stage this year [2]. As a key step, the continuous-wave high charge state heavy ion RFQ [3] is tested in the laboratory of the Institute of Modern Physics. The main parameters of the RFQ are listed in **Table 1**. Because of the low frequency, the four-rod structure is adopted to this machine. In the past decades, some CW heavy ion RFQs have accumulated many operation hours, such as the TRIUMF RFQ [4] and the RILAC II RFQ [5]. The new HLI RFQ designed for CW operation also has been tested in the recent years [6]. These machines provide many experiences to the commissioning of the SSC-LINAC RFQ.

The SSC-LINAC RFQ has been delivered to the IMP in the first season of 2013. Then it was tested there and has been commissioning with high RF power and high charge state beams. The RFQ with its beamline is shown in Figure 1. The cavity measurement has been done again in the laboratory of IMP, including the measurement of RF performance and the quality of the electric field distribution. Comparing with the proceeding reported in IPAC 2013 [7], the method and results of the measurement have been improved. Further, the high power RF test is carried out from pulse mode to CW mode. It has reached 35 kW CW operation at the end of May in this year. Finally, the first beam transportation results were obtained by using $^{16}O^{5+}$ and $^{40}Ar^{8+}$ beams. All the results of these tests and measurements will be represented in this paper.

Table 1: Main Parameters of the SSC-LINAC RFQ [3]

Parameters	Values
Frequency / MHz	53.667
Ratio of charge to mass	1/3-1/7
Design Current / pmA	0.5
Inter-vane voltage / kV	70
Duty factor / %	100
Input energy / (keV/u)	3.728
Output Energy / (keV/u)	143.0
Length of electrodes / mm	2508.46

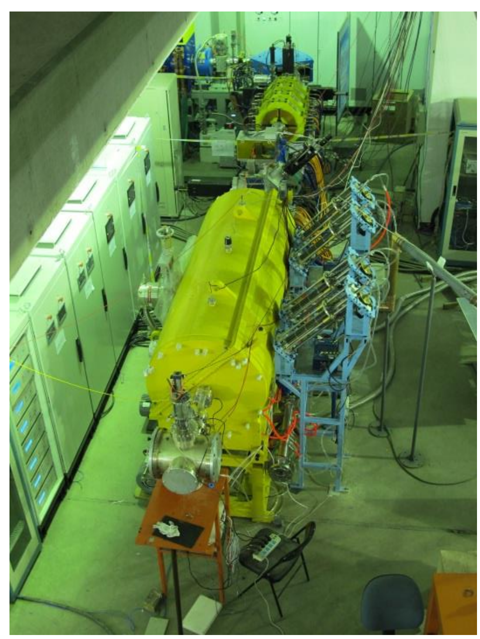

Figure 1: The beamline of the first stage of SSC-LINAC, in which the yellow cavity is the RFQ.

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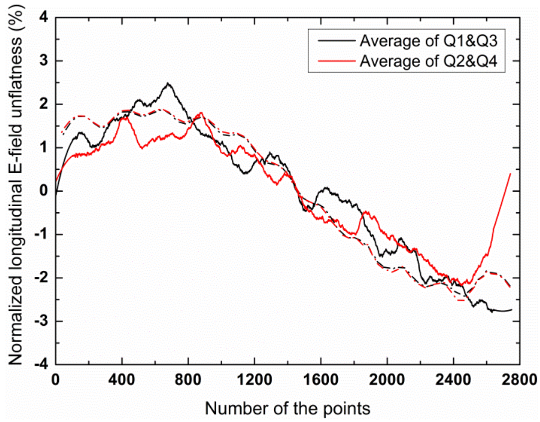

Figure 2: The unflatness of the electric field measured at the places which is 20 mm to the beam axis.

CAVITY MEASUREMENT

The frequency of the cavity without tuning is measured to be 53.607 MHz at 25 ℃. It is 60 kHz lower than the operation frequency. The Q_0 value at this temperature is 6440. The tuning range of the plunger tuners is measured when they are inserted together by the same length. They could raise the frequency of the cavity by 125 kHz at maximum, agreeing with the simulation results.

The electric field distribution is measured again, using a polytetrafluoroethylene (PTFE) bead instead of the block [8] to be the perturbation body. Because it is found that the perturbation induced by the PTFE bead is much smaller than the block while the ratio of signal to noise maintains large. Then the measurement error of the bead is much smaller. However, the sink of the bead caused by gravity when it moves to the center of the cavity brings another error to the measurement. Analysis from the transverse electric field distribution between the electrodes, the error caused by gravity could be as high as 20% of the measured field strength, much serious than other errors. Then it should be corrected in the data analysis. By linear approximation, the gravity effect could be offset by averaging the field strength of the opposite quadrants. The correction method is discussed in ref. [8]. Figure 2 shows the unflatness of the field after correction. The measurement result is in line with the simulation one. The unflatness of the field is ±2.5%. Since the quality of the field is acceptable, there is not necessary to tune the field of this RFQ.

HIGH POWER COMMISSIONING

The RF power of the SSC-LINAC RFQ comes from a 60 kW solid state amplifier. The commissioning started from pulse mode with the duty factor of 5%. The amplitude of the signal source and the pulse length rise gradually to increase the average power of the cavity. There is little sparking observed in the commissioning. The simulated power consumption of the cavity is 31 kW for $^{238}U^{34+}$ beams, and then the maximum pulse power has reached 40 kW during the test. The inter-vane voltage is

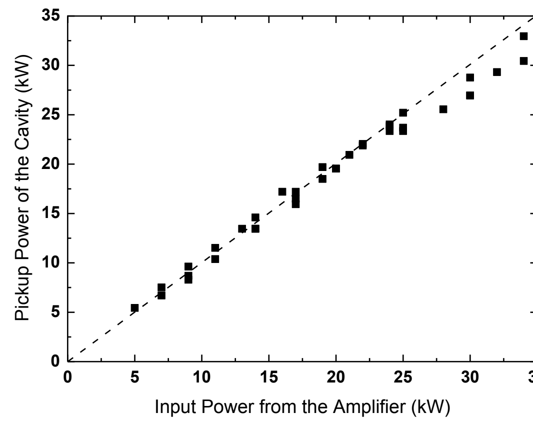

Figure 3: Comparison of the pickup power of the cavity and the input power from the amplifier.

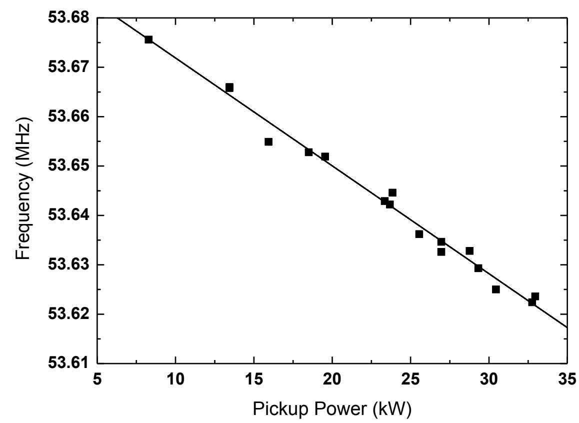

Figure 4: Frequency shift of the cavity without tuning during CW operation.

measured by detecting the bremsstrahlung spectrum emitted from the electrodes. It determines that the cavity needs 35 kW to generate 70 kV inter-vane voltage for the acceleration of beams with the ratio of charge to mass of 1/7.

The commissioning turns to CW mode after the pulse mode test of 30% duty factor. By now the input power from the amplifier has reached 35 kW CW, but the pickup power from the cavity is lower in high power range, as shown in Figure 3. It could be seen that when the power is lower than 25 kW, the pickup power almost equals to the input power, which means the power consumptions of the coupler and other factors are small. However, when the power is higher than 25 kW, the pickup power is lower than the input power. Actually, the difference of the power is consumed on field emission electrons and the plasma generated due to the deterioration of vacuum in the coupler. Such phenomenon brings some damages to the welding point of the coupler.

The frequency shift and water temperature are monitored during CW mode operation. As shown in Figure 4, the frequency and power of the cavity keep linear during the test. The rate of frequency shift is 2.18 kHz/kW. This shift will be offset by the plunger tuners with automatic frequency controlling system. Figure 5

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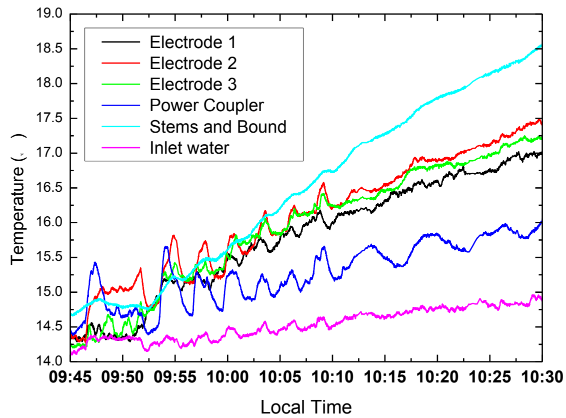

Figure 5: Temperature of the cooling water, except the inlet water, the data of other curves is obtained at the exit of each cooling channel.

represents the temperature variation of the output cooling water when the power increases from 0 to 30 kW CW. The temperature of water comes from the stems and bound raises more quickly than those from other components because all the stems and bound share the same inlet and outlet water channel. The total increment of the temperature of the water is 4.5 ℃ when the power is 35 kW CW.

BEAM COMMISSIONING

The SSC-LINAC RFQ has been tested by $^{16}O^{5+}$ and $^{40}Ar^{8+}$ beams on CW mode. Since some beam diagnostics facilities has not gone into operation, only the transmission efficiency and energy of the output beams could be measured by now. The efficiency is measured by two faraday cup located at the upstream and downstream of the RFQ respectively, while the energy of the beams is obtained by Time of Flight (TOF) method, using two Fast Current Transformer (FCT). The first result comes from the transportation of $^{16}O^{5+}$ beams. The transmission efficiency is 83% when the input current is 180 μA. The result is lower than estimation because the distance from the faraday cup to the exit of the RFQ is 783 mm. The beam spot there is larger than the area of the faraday cup. Then some particles weren't received by the cup. In the $^{40}Ar^{8+}$ beam experiment, a larger cup has been installed on the beamline. As a result, the transmission efficiency of $^{40}Ar^{8+}$ is as high as 94% when the input current is 210μA. Figure 6 shows that the efficiency decreases when the power is lower than 17 kW. This agrees with the simulation result that the power consumption for acceleration of the beams with the ratio of charge to mass of 1/5 should be 17.9 kW. On the beam energy, the $^{16}O^{5+}$ is 141.89 keV/u at the exit while the $^{40}Ar^{8+}$ is 142.78 keV/u. Both satisfy the requirement of the SSC-LINAC project.

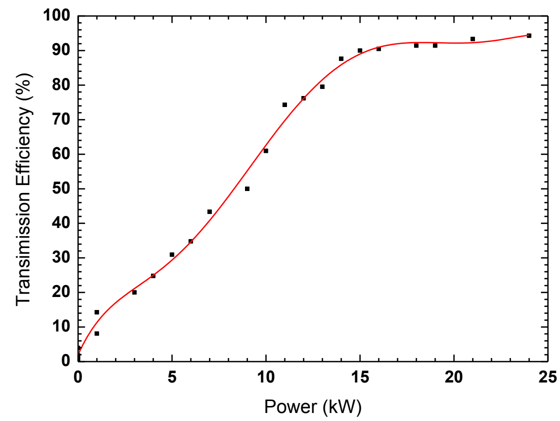

Figure 6: Transmission efficiency of the $^{40}Ar^{8+}$ beams in different cavity power.

CONCLUSION

The tests and commissioning of the SSC-LINAC RFQ are reported in this proceeding. As a result of the cavity measurement carried out in the lab of IMP, the frequency of the cavity without tuning is 53.607 MHz at 25 ℃, and the Q_0 is 6440. The four plunger tuners could raise the frequency of the cavity by 125 kHz at maximum. The bead perturbation method has been applied to check the distribution of the electric field. The unflatness of the field is ±2.5%. The cavity has been tested with 35 kW CW power in the high power commissioning. The total temperature increment of the cooling water is 4.5 ℃. Finally, the transmission efficiency of $^{40}Ar^{8+}$ beam reaches 94%, and the output energy is 142.78 keV/u, which is very close to 143 keV/u.

REFERENCES

[1] Yuan He, Zhijun Wang, Chen Xiao and et al, Proc. IPAC2011, p. WEPS052, 2011.

[2] X. Yin, W. Lu, X. Zhang and et al, This proceeding, THPME026.

[3] G. Liu, Y. R. Lu, Z. Wang and et al, Nucl. Instr. and Meth. A, 701(2013), p. 186

[4] R. L. Poirier, R. Baartman, P. Bricault and et al, Proc. of XX International Linac Conference, 2000, FR102.

[5] K. Yamada, S. Arai, Y. Chiba and et al, Proc. of LINAC 2010, 2010, TUP070.

[6] P. Gerhard, W. Barth, L. Dahl and et al, Proc. of IPAC'10, 2010, MOPD028.

[7] G. Liu, Y. R. Lu, Z. Wang and et al, Proc. of IPAC2013, 2013, THPWO047.

[8] LIU Ge, LU YuanRong, YIN XueJun and et al, SCI. CHIN. Phys. Mech. Astro., 57(2014), 1311.