HIGH RF POWER TEST OF COUPLED RFQ-SFRFQ CAVITY*

W. L. Xia, Z. Wang#, Y. R. Lu&, K. Zhu, J. Zhao, F. J. Jia, S. L. Gao, J. E. Chen,
IHIP, SKLNPT, Peking University, Beijing, China

Abstract

A new combined accelerator that couples radio frequency quadrupole (RFQ) and separated function radio frequency quadrupole (SFRFQ) in a single cavity has been designed and manufactured. Recently, the performance of the cavity under high RF power was tested with an upgraded RF power source. The inter-vane voltages of both RFQ section and SFRFQ section were measured by using high purity germanium detector and the corresponding measurement system. The measured shunt impedance is about 546.9 kΩ·m, which means the cavity needs 19.5 kW for the designed inter-vane voltage of 65 kV. The results are well consistent with the cavity design.

INTRODUCTION

Based on the simulations and experiments of the former ISR-1000 RFQ and SFRFQ structure [1-4], we have been exploring the feasibility of coupling the two different structures in a single cavity. The coupled structure combines both the advantage of RFQ for better beam acceptance of low energy ions and the advantage of SFRFQ for higher accelerating efficiency, and will significantly shorten the length of the accelerator for the same beam energy gain in RFQ. The beam matching between RFQ and SFRFQ were realized and shown in the dynamic analysis [5] not only for the transverse emittance also for the longitudinal synchronous phase and beam energy. Thus, the coupled RFQ-SFRFQ (CRS) cavity can accelerate 5 mA He^{+} beam from 7.5 keV/u to 201.2 keV/u in 2.5 m cavity. Fig. 1 shows the schematic drawing of the CRS linac [6]. The design parameters of CRS cavity are listed in Table 1.

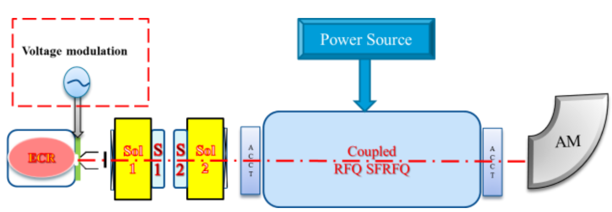

Figure 1: Layout of CRS linac.

Recently, the CRS cavity has been manufactured and tested under low RF power. Based on the measured RF features of the cavity, such as frequency, Q value and electric field distributions, we adjusted the conditions of an upgraded RF power source and set up a measurement system for high RF power test of CRS cavity.

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#wangzhi@pku.edu.cn;
&yrlu@pku.edu.cn

Table 1: Main Design Parameters of CRS Cavity

	RFQ	SFRFQ
Frequency (MHz)	25.5	25.5
Inter-vane Voltage (kV)	65	65
Current (mA)	5	5
Duty Factor	1/6	1/6
Input Energy (keV/u)	7.5	105.7
Output Energy (keV/u)	105.7	201.2
Cells Number	33	10
Length (m)	1.48	1.00

CRS STRUCTURE

Because of the low operating frequency, four-rod structure in RFQ section was adopted. The two sections use the same shape supporting rings, considering the capacitance between SFRFQ electrodes is larger than that between RFQ electrodes, we have shortened the distance between the supporting rings in SFRFQ section to maintain the similar RF features of the two sections. Based on the electromagnetic simulation and optimization, the final structure was determined. The cavity has been manufactured and assembled as shown in Fig. 2, the electrodes connect to 14 supporting rings, the eight for the RFQ and another six for the SFRFQ section. The transition region, where RFQ electrodes directly connect to SFRFQ electrodes, should maintain good electrical conductivity so that the two sections will be resonated in the single cavity.

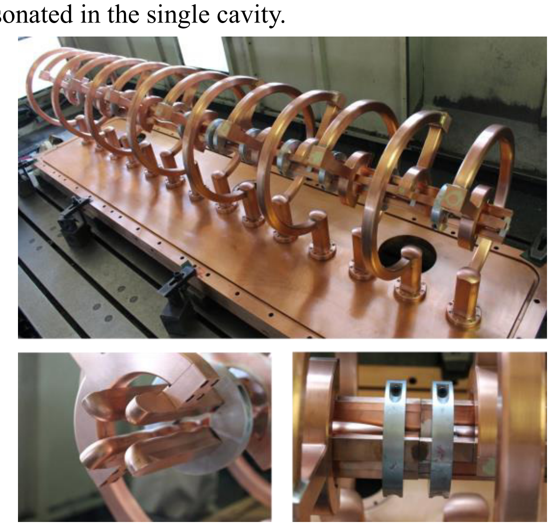

Figure 2: Structure of CRS cavity.

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BENCHMARKING THE MEASUREMENT

Before the high RF power test, the performance benchmarks of the cavity and the power source should be determined.

RF Features of CRS Cavity

The S parameters of the cavity were measured by using vector network analyzer Agilent E5061BEP-235 (50 Ω). Since the characteristic impedance of the RF power source is 75 Ω, via adjusting the shape and rotating direction of the coupler, we have determined the crossing point of S11 trace and pure resistance axis in the Smith chart as the resonant frequency of the cavity. The S11 and S21 traces are shown in Fig. 3.

S11 have been measured at three ports of coaxial tube with different distance to the coupler, and the crossing points in the Smith chart maintain the same coordinate around 75 Ω. Thus the measured resonant frequency was determined to 25.418 MHz, and the loaded Q factor is 1874.2.

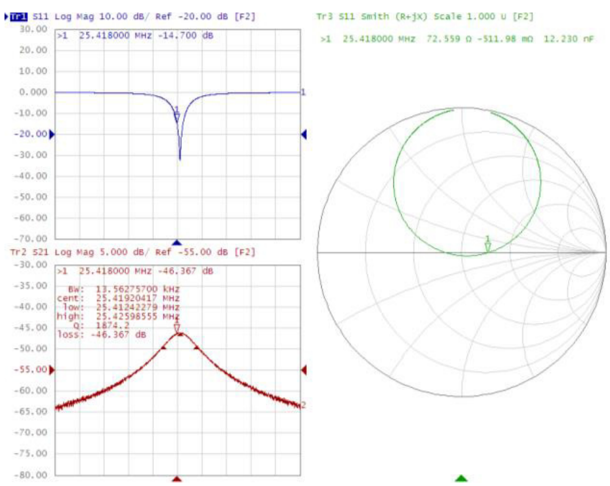

Figure 3: S parameters of CRS cavity.

RF Power Source Performance

A RF power source has been upgraded and tested with 75 Ω dummy load (DL) under the rated output power. The excitation source was adjusted to 25.418 MHz, and the test results are listed in Table 2.

Table 2: Test Results of RF Power Source

Duty Factor	**1/6**	**CW**
Power (kW)	30	20
SWR	1.1	1.1
DL △T (℃)	2.6	10.7
DL Absorption (kW)	5.2	21.4

During the test, the RF power source can maintain stable output power and safe operation with the upgraded interlock control system, and it can be self-recovered from the interlock protection.

HIGH RF POWER TEST

According to the measurements of the cavity RF features and the adjustment of RF power source, the high RF power test of the cavity was carried out under 1/6 duty factor. The aim of the high RF power test of the cavity was to measure the inter-vane voltage and the corresponding power consumption, and a measurement system was set up to achieve this goal.

Measurement System

The high voltage between the electrodes of the cavity under high RF power can generate X-ray due to the radiation caused by field emission. The maximum kinetic energy of electron E_{max} is given by $E_{max}=e\cdot U$, where U denotes the inter-vane voltage. Thus the inter-vane voltage can be derived from the highest energy in X-ray energy spectrum.

Based on the principle, the high purity germanium detector with amplifiers and multichannel analyzer (MCA) were used to measure the X-ray energy spectrum. The measurement system is presented in Fig. 4.

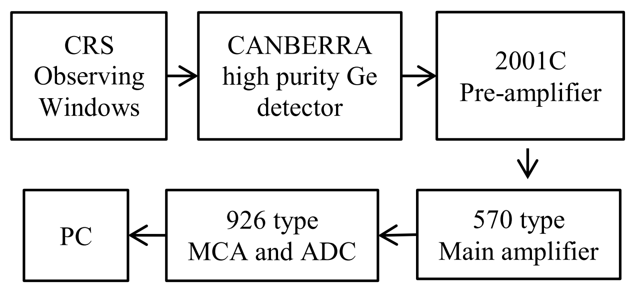

Figure 4: Layout of the measurement system.

Measurement Results

The X-ray energy spectrum was measured with different input RF power by using a high purity germanium detector close to the observation windows. The spectrums detected at RFQ section and SFRFQ section are presented in Fig. 5 and Fig. 6, respectively.

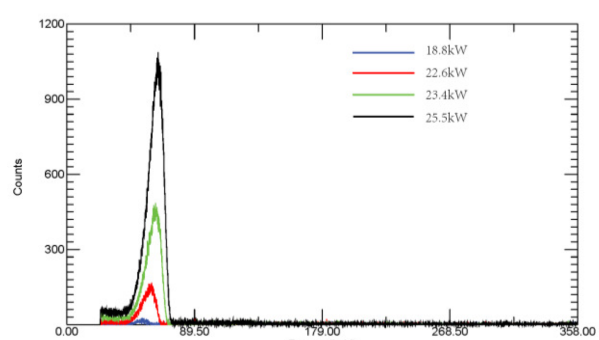

Figure 5: Spectrums measured in RFQ section.

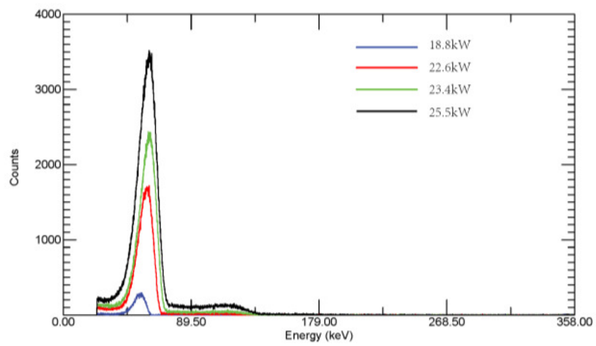

Figure 6: Spectrums measured in SFRFQ section.

ANALYSIS AND DISCUSSION

According to the measurement results, some key points were proposed and analysed. Comparing the spectrums in Fig. 5 and Fig. 6, it is concluded that:

- In the same RF power consumption and counting time, the higher capacitance in SFRFQ section leads to more field emitted electrons, the counts in SFRFQ section was over three times higher than that in RFQ section.
- The high energy bench in the spectrum, especially in SFRFQ section, indicates the high RF power results in high-energy electronics noise.
- Evaluating from the spectrums of the two sections under the same RF power consumption, the inter-vane voltages of the two sections were kept consistent as well as the balanced power distribution were built between the two structures.

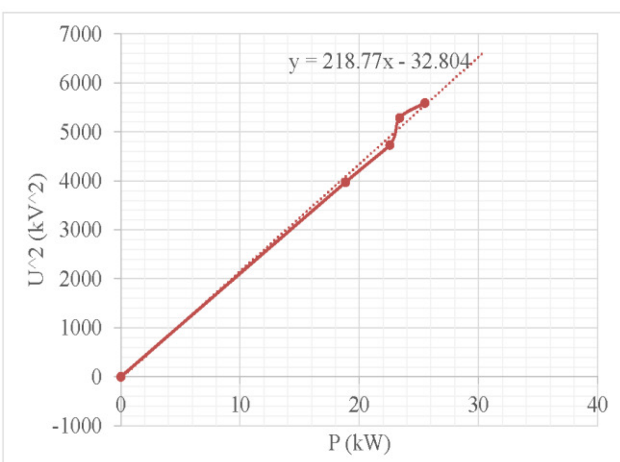

Figure 7 : Relation between inter-vane voltage and power consumption.

Since the two structures have the same inter-vane voltage, we can evaluate the shunt impedance of the cavity from the linear relation between the square of inter-vane voltage and corresponding power consumption. AS shown in Fig. 7, the slop of the linear fitting indicates the shunt impedance per unit length. Thus, the shunt impedance of CRS cavity is 546.9 kΩ·m. According to the relation, when the input power reaches 19.5 kW, the inter-vane voltage is 65 kV. The comparisons of simulation and measurement of CRS cavity are shown in Table 3.

Table 3: Comparisons of Simulation and Measurement Results of CRS Cavity

	Simulation	Measurement
Frequency (MHz)	25.350	25.418
Q factor	4326.3	3748.4
Power (kW)	16.2	19.5
Shunt impedance (kΩ·m)	651.0	546.9

CONCLUSION

The high RF power test of the coupled RFQ-SFRFQ cavity are presented in this paper. The measured results verified that RFQ and SFRFQ can be coupled in the same resonant frequency in one cavity. Because of the situation of non-perfect electric conductor, the measured power loss was 20% higher than the simulation value, and the measured shunt impedance was 84% of the simulation value.

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