OPERATING STATUS OF INJECTOR II FOR C-ADS PROJECT

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Abstract

The Radio Frequency Quadrupole system has been designed and constructed for C-ADS (Chinese Accelerator Driven System) Injector II in Institute of Modern Physics (IMP), Chinese Academy of Sciences, which has been running for more than one year until now. It is a quadrilateral four-vane resonator with two equal couplers operating in CW mode. In the paper, RF system upgrade will be presented in detail，especially the two-port configuration was introduced and the conditioning based on two new sets of solid-state amplifier instead of the original tetrodes power source due to system hardware upgrade are described in the paper.

INTRODUCTION

Since 2011 Chinese Accelerator Driven System (C-ADS) project has been developed in order to solve the nuclear waste disposition and energy shortage crisis [1], which carried out by two institutes from Chinese Academy of Sciences. According to the arrangement of the project, IMP (Institute of Modern Physics) would build a 25-50 MeV demo facility named Injector II by the end of 2016. Injector II consists of Ion Source, LEBT (Low-Energy Beam-Transport), RFQ, MEBT (Medium-Energy Beam-Transport) and SC (Superconducting) section. And as the first accelerator, a four-vane RFQ which accelerated CW 10mA proton beam up to 2.1 MeV and with an operating frequency of 162.5MHz in June 2014, whose power source is traditional tetrode amplifier at the beginning of operation. Now two 80kW solid-state amplifier (SSA) as new power source instead of tetrode one, and by the end of May, 2016, the conditioning had been completed after RF system setting up. The RFQ cavity is shown in Fig. 1.

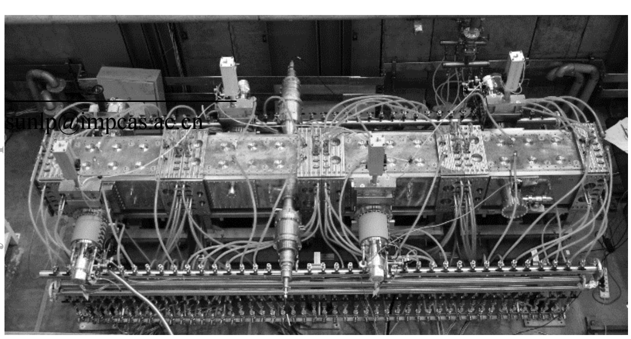

Figure 1: The four-vane RFQ cavity with two couplers.

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NEW POWER SOURCE

According to the design for C-ADS, the failure time are limit strictly by several hours in one year. And previous tetrode amplifier has some problems, such as high sparking risk in input/ output cavity, running pressure while high intensity current due to no circulator and so on. However, since the dissipated power in RFQ cavity is very high, the SSA must be designed to output very high power in spite of two couplers feeding power into resonator. Finally, two new 80kW SSA were decided considering the power margin and beam loading, which were developed by two different manufacturers in order to verify the technologies on high power combining.

Figure 2: Two sets of 80kW solid-state amplifier.

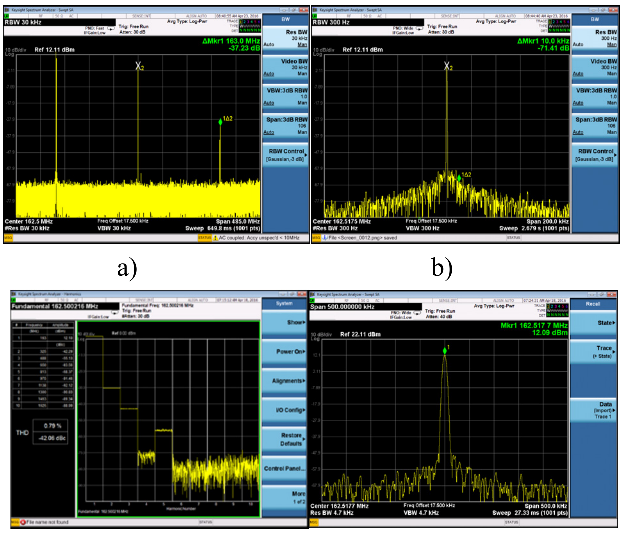
New two power sources delivery the power to the cavity other than old tetrode amplifier, which split the power into two couplers from one power source.

According to the design of RFQ, new parameters of SSA were decided and optimized, which is shown in Table 1, and every module in it must stand the long-term full power reflection and hot swapping (insertion and extraction without ceasing electricity).

Table 1: Specifications of Solid-State Amplifier

Requirement	Target value	Comment
Nominal frequency	162.5MHz	±1MHz
Duty cycle	100%	Pulsed mode possible.
Max. transmitted power	80kW	VSWR≤1.5.
Max. reflected power in operation	10.5kW	Full power reflection possible.
Output noise	≤-60dBc	Dummy load
Harmonic suppression	≤-30dBc	Dummy load
Amplitude stability	$\leq\pm1\times10^{-3}$/24h	Close loop
Phase stability	$\leq\pm1\times10^{-3}$/24h	Close loop
RF impedance	50 ohms	All components

The two sets of SSA were send to IMP April, 2016, and the primary measurements were completed while SSA connected with dummy load. As examples, the measured harmonic and noise suppression were presented in Fig. 3, which is in agreement with the designed ones. The a) and b) mean -37.2dB and -71dB results from one SSA, and c) and d) show -42.29dB and -61dB results of the other one.



a) b) c) d)

Figure 3: The harmonic and noise suppression results.

So far, two sets of SSA appear to meet the requirements of C-ADS operation, and a long-term stability was shown to be better than previous tetrode one.

TWO-PORT CONFIGUREATION [2]

According to RFQ beam dynamics design, nearly 31.5 kW beam power and 97 kW dissipation power of the RFQ cavity will be transmitted by couplers. If the two couplers are set incorrectly, the total power of 128.5 kW may concentrate on one coupler and may exceed the capacity of single coupler. Therefore, proper configuration of the two couplers become a critical technical issue for the stable running of the whole RF system.

According to the RF theory, the loaded Q_L of a cavity with two couplers is:

$$\frac{1}{Q_L} = \frac{1}{Q_O} + \frac{1}{Q_{ext,1}} + \frac{1}{Q_{ext,2}} \quad (1)$$

$$Q_O = (1+\beta)Q_L \quad (2)$$

then

$$\beta = \frac{2Q_O}{Q_{ext,1,2}} \quad (3)$$

where Q_O and Q_{ext} are unloaded and external quality factor, respectively. The coupling constant β of the cavity without beam must meet the requirement $\beta = 1 + Pi/Pc$ so that the couplers are in critical coupling condition when beam is accelerated, where Pi and Pc are the beam power and cavity power respectively. According to the definition of coupling constant, for each coupler

$$\beta_{1,2} = \frac{Q_O}{Q_{ext,1,2}} = \frac{\beta}{2} \quad (4)$$

therefore, for the acceleration of 15 mA proton beam β=1.32, and for each coupler $\beta_{1,2} = 0.66$.

When setting up the two couplers a vector network analyser (VNA) is utilized to measure the S_{11} scattering matrix which is related with coupling constant [3], and the two couplers ports are measured separately at the same time. The measured coupling constant $\beta^*_{1,2}$ has a relationship with the real $\beta_{1,2}$ as follows

$$\beta^*_{1,2} = \frac{\beta_{1,2}}{1+\beta_{2,1}} \quad (5)$$

Furthermore, the coupler port must be open when the other coupler is measured.

Finally, we set the S_{11} scattering matrix of each coupler as -7.3 dB to correspond the coupling constant β of 0.66, and this configuration has never been modified during the subsequent conditioning and beam commissioning. According to the S_{11} scattering matrix the line impedance of each port is 33 ohms. The RF system with two coupler ports has been simulated with Microwave Studio to verify the two-port configuration is correct.

COUPLERS

Based on experiences from the previous coupler design for a 30 kW one-meter prototype RFQ cavity [4], a few modifications have been made to the two new couplers designed for the actual cavity. The two new couplers with higher power have been optimized for several times, especially, for S11 parameter and dielectric loss of ceramic window specially. The most significant changes are the bowl-shaped window and the optimized scattering parameter. The design goal is shown in Table 2.

Table 2: Specifications of New Couplers

Requirement	Target value	Comment
Nominal frequency	162.5MHz	±1MHz
Duty cycle	100%	Pulsed mode possible.
Max. transmitted power	60kW	Full reflection to be withstood on tetrodes AMP.
Max. reflected power in operation	10.5kW	Over-coupling (beam power).
Line impedance	50.0 ohm	RF network impedance.

The cross section view of the couplers is presented in Fig.4, it consists of an outer coaxial conductor, an inner conductor and a bowl-shaped ceramic window. The special shape of ceramic serves for three purposes, first of all, the impedance match for transmission line of 50 ohms is easier due to the minimum dielectric loss at longitudinal space. furthermore, it can diffuse the pressure on the ceramic surface for mechanical properties when the cavity is pumped. Last but not least, the different location between inner and outer conductor was considered to set sealing spring, which provide convenience for disassembling without vacuum damage.

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An extra quarter-wave part of EIA 6 1/8" waveguide is attached to the rear of the couplers (as shown in Fig. 4) in order to promote cooling structure and obtain a better RF property (S_{11}) on the port of forward power. The length of it is calculated with CST Microwave Studio to be 510.4 mm, and simulated result shows S11 can be reduced to about -37 dB, which means a perfect matching.

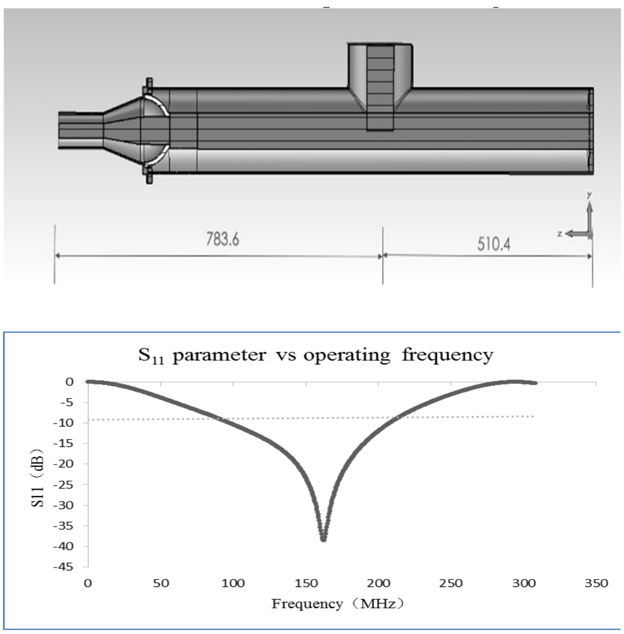

Figure 4: The section view of coupler and its S_{11} Result with the matching port.

CONDITIONING

Considering the previous operating experiences [5], a new process of conditioning of RF system started on April 2016, the low power of several hundreds of watts was injected into cavity at the beginning, and the power of 97 kW in CW mode have reached after two weeks. Until now, the 10mA pulsed beam has been accelerated several times and all the parameters well meet the commissioning requirements of the RFQ. Fig. 5 shows the relationship between the inter-vane voltage of the RFQ and the input power obtained by simulation and measurement, and it reveals the shunt impedances the two way are nearly equal which is about 45.6 kΩ.

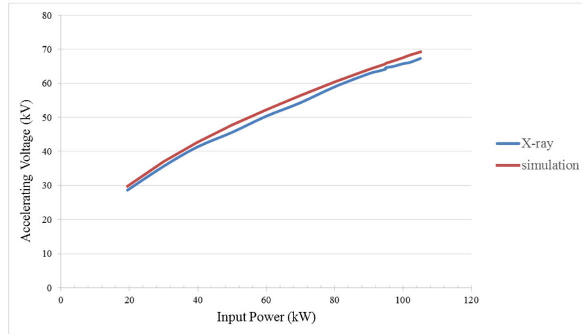

Figure 5: The Accelerating Voltage Calibration from Simulation and X-ray Radiation.

A final note about new SSAs is that the gain curve must have some difference between two machines resulting from the design of power modules, power combiners, control, LLRF system and so on. So a balance power point chosen is at rated power level which is the same output power at that time.

SUMMARY

The preliminary design of the new SSA has been accomplished and verified, and the main parameters of RF system were analysed and calculated by the electromagnetic code microwave studio. the main features in the RF system was the two-port configuration which indicates a new method to solve high power delivery by two identical, and subsequent successful acceleration of 10 mA pulsed beam proves the design and manufacture of the RF system are all correct and can well meet the requirements of the RFQ accelerator.

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