STUDY OF CSNS RFQ DESIGN *

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Abstract

A new 324MHz Radio Frequency Quadrupole (RFQ) linac used for the project of China Spallation Neutron Source (CSNS) is being designed. The designed injection and output energy are 50keV, 3.0MeV, respectively. The pulsed current is 40mA though the required current asked from CSNS at its first stage is 15mA. The pulsed width is 420 μs with a 50% chopping ratio and repetition rate 25Hz. The transverse structure of CSNS RFQ will be basically same as the former RFQ used for Accelerator Drive sub-critical reactor system (ADS), but the length of 3.62m is shorter comparing to the length of 4.75m of the former.

INTRODUCTION

The R&D of some key components for CSNS [1] is now under way. The beam power of CSNS for its first stage is designed to 120kW with the extracted beam energy of 1.6GeV and repetition of 25Hz. The beam is firstly accelerated by a linac to the energy of 81MeV and then boosted to 1.6GeV by a rapid cycling synchrotron (RCS). The pulsed beam current and length required for the linac at its first stage are 15mA and 420 μs , respectively. In view of the upgrade capability of CSNS, the designed pulsed current of CSNS RFQ is chosen to be 40mA. With this beam current, the beam power of CSNS could reach 500kW.

At IHEP, we have already constructed a 352.2MHz RFQ [2,3] with the output energy of 3.5MeV and pulsed beam current of 50mA. Commissioning of the RFQ is being carried out. In the case of beam duty factor of 0.2%, about 40mA pulsed beam current at exit of RFQ is got soon at its third operation. A maximum transmission of 92% has arrived up to now [4]. Due to the choice of the linac RF frequency of 324MHz for CSNS instead of 352.2MHZ, a new RFQ is needed. Based on the success and experience of the former RFQ, the new RFQ structure will keep same as much as possible with the former. The CSNS RFQ will still consist of two resonantly coupled segments and each segment consists of two sections that technically connected together [5,6]. 4 dipole stabilization rods will be installed on the inside side of the end plates and each side of the coupling plate. Comparing to the length of 4.75m of the former RFQ, the length of the CSNS RFQ is 3.62m, which is only about 3.9 times long as the wavelength of RF. With such a length, one segment RFQ structure should be also feasible. However, we still prefer to choose two resonantly coupled segments RFQ structure. The benefit from this choice is that the quadrupole modes interval almost double and the length of dipole stabilization rods become shorter. The price is the additional power dissipation on the coupling plate (about 2 kW) and a little more complexity of the structure.

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DYNAMIC DESIGN

In Table 1, the main RFQ design parameters and their value are listed. Both the vane-tip curvature ρ_t and the average bore radius r_0 are kept constant along RFQ, and the ratio of them is 0.89. For the former RFQ, this ratio is taken to unit. As known, the less the ratio is, the less field components of the multi-pole modes are of. To take a constant vane-tip curvature ρ_t facilitates to the machine of vanes by a formed cutter, while a constant average bore radius r_0 benefits the tuning of field distribution.

Table 1: Main RFQ Design Parameters

Parameters	**Value**
Frequency	324 MHz
Injection energy	50 keV
Output energy	3.0 MeV
Pulsed beam current	40 mA
Beam duty factor	1.05%
Inter-vane voltage V	80 kV
Average bore radius r_0	3.565 mm
Vane-tip curvature ρ_t	3.173 mm
Maximum surface field	31.68 MV/m (1.78Kilp.)
Input norm. rms emittance	0.2 pi.mm.mrad
Vane length	3.603 m

In Fig. 1, some parameter variation versus cell number is shown. In the figure, a stands for the minimum bore radius, m modulation factor, B focusing strength, W synchronous energy and ϕ_s synchronous phase. With this set of parameters, the transmission of the beam got by

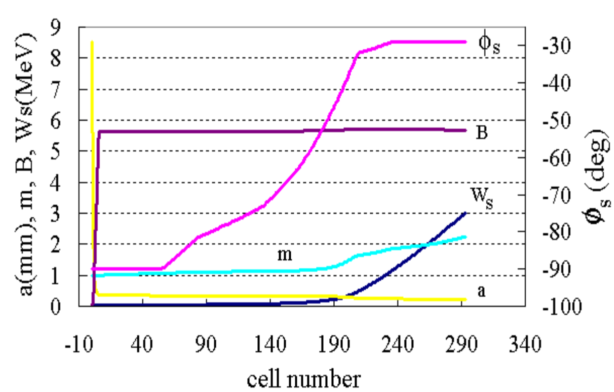

Figure 1: Parameter cell variation.

PARMTEQM is about 97.1%. Beam dynamics in the RFQ is shown in Fig. 2. In Fig.3, the beam distributions in the phase space at the entrance and exit of RFQ are given. In the simulation, the input particle distribution used is a 4D waterbag transversally, with uniform phase distribution and no energy spread longitudinally. The transverse normalized rms emittance and the longitudinal rms emittance for the output beam are 0.2002pi.mm.mrad and 0.1143MeV-deg, respectively. Beam dynamics is also checked with the code TOUTATIS got from Dr. Romuald Duperrier, and a 99.4% transmission is given by this code. Fig.4 shows the beam transmission as function of RFQ length got by code TOUTATIS.

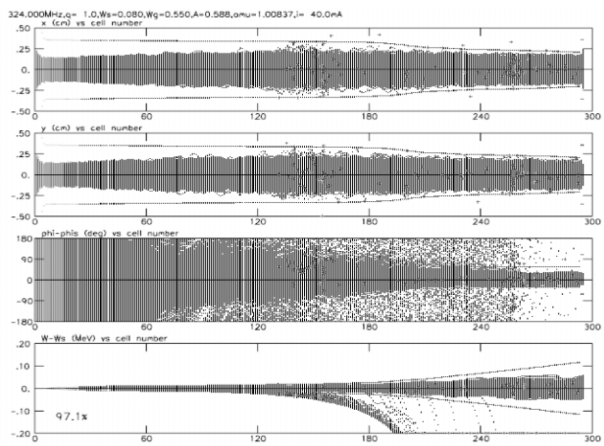

Figure 2: Beam dynamics in RFQ for a current of 40mA.

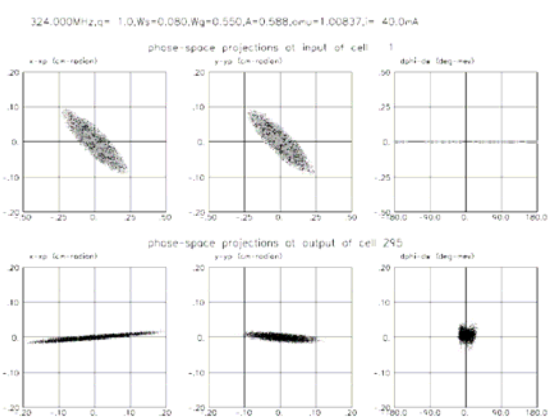

Figure 3: Particle distribution in phase space at the input and output cells.

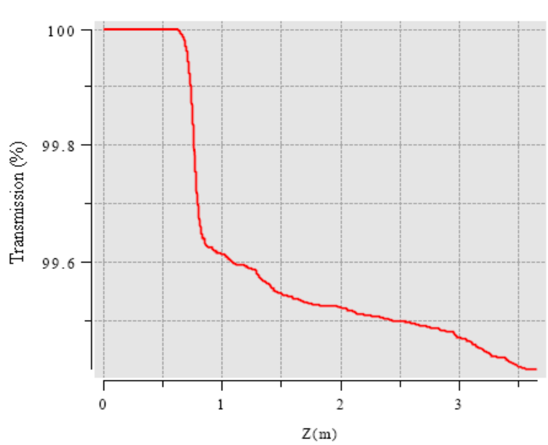

Figure 4: Beam Transmission versus RFQ length got by code TOUTATIS.

RFQ STRUCTURE

Figure 5 shows one quadrant of the RFQ transverse shape, which is almost same as the former one. In order to facilitate the drilling of water-cooling channel in the vane, comparing to the former RFQ, the width of vane base is increased to be 20mm from 18mm. When the tuners are flushed with the inside of RFQ, the cavity cut-off frequency is designed to 322.7MHz, the remnant 1.3MHz frequency difference will compensate by the tuners. 48 plug tuners will be homogeneously distributed in the four sections with 12 tuners in every quadrant and in every section. The diameter of the tuner is chosen to 60mm, and the nominated penetration of tuner is about 4.9mm. Though the penetration of tuner will lead to the additional power dissipation on the tuners and the oscillation of the filed along RFQ. However, in practice, without the 1.3MHz frequency difference, it will be very difficult to tune the RFQ with a little big positive frequency error brought in the cavity machining process. The power dissipation on the wall got by SUPERFISH for one

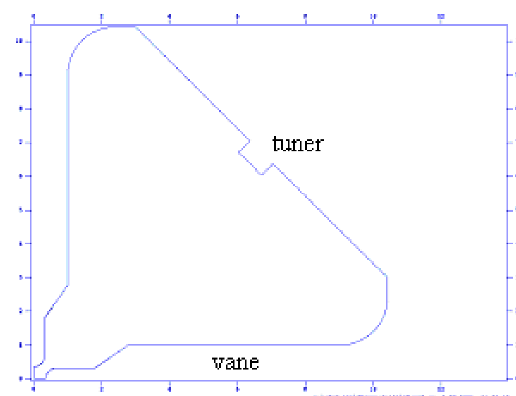

Figure 5: One quadrant of the RFQ transverse shape.

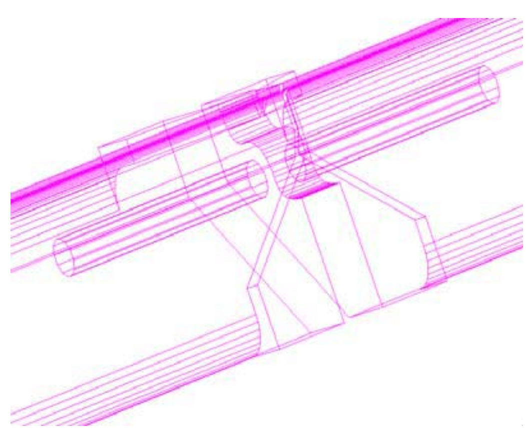

Figure 6: The simulated 3-dimension coupling cell.

quadrant of the RFQ is about 193W/cm, so the total power dissipation of the RFQ is about 279kW. If taking a multiplying factor 1.4 for the real RFQ, the power dissipation is about 390kW. Taking the beam loading into account, the power asked for RF system is about 510kW.

Three dimensions simulations are necessary to determine the shape and size of the beginning cell, the coupling cell, the end cell, the dipole stabilization rods and the vacuum port, etc. In order to counteract the local cut-off frequency falling at the vacuum port position, the vacuum ports will be still machined separately like the former, and then brazed together with the RFQ bulk, holding the vacuum port a little intrusion to the RFQ cavity like the tuner. In Fig. 6, the simulated 3-dimension coupling cell is shown. The coupling cell includes the undercuts, the dipole stabilization rods, the coupling plate and the coupling gap. To determine the undercut, the local cut-off frequency should keep same as the cavity quadrupole cut-off frequency. Where the dipole stabilization rod located is in the place it has no influence on the quadrupole cut-off frequency. The rod diameter is decided by mechanical request while the length is determined on the basis that the frequency interval between the operation mode and its two neighbour dipole modes keep same as much as possible. The coupling gap is determined by the frequency interval between the operation mode and its two neighbour quadrupole modes. Since the gap width is very small comparing with the whole length of the RFQ, special attentions must be paid in meshing the gap during 3-dimension simulation. Otherwise, large error will produce in determining the gap width. In addition, before determining the end cells and coupling cell through 3-dimension simulations, it is also necessary to simulate a basic RFQ section without undercuts. The frequency result got by this preparing simulation can then be taken as a criterion for the afterward simulations. So the errors brought by the difference between 2-dimension simulation and 3-dimension simulation could be almost avoided.

DISCUSSIONS

There are generally two ways to suppress the dipole field components in the RFQ. One is to install the dipole stabilization rods on the end plate and the coupling plate, another is to use PI-mode stabilizing loops cross the vanes. We will still adopt the first method as we used for our former RFQ. Comparing to the second way, the main advantages of this method are as following. First, the power dissipation is much less than that by using PI-mode stabilizing loops. The total power dissipated on all rods for our former ADS RFQ is 5kW with about 5/12kW on each rod. When the RFQ runs in pulsed mode with just several percent duty factor, with this value of power dissipation, the water-cooling channel is not machined in the rods. The rods are cooled indirectly through the cooling water circulating on the end plates and the coupling plate. Second, the influence on the quadrupole cut-off frequency brought by the rods is negligible, while the variation of quadrupole cut-off frequency arose by the loops is very large, and the frequency got by the simulation is highly different from the real case. The experience from the former RFQ shows that the 3-dimension simulation results are almost same as the RFQ reality. So, for the CSNS RFQ, we intend to construct directly the real RFQ without any cold models. The shortcoming of adopting rods is that the frequency interval between the operation mode and the neighbour dipole mode is just about 5MHz comparing to the large interval of about 30MHZ for the case of using loops. However, the success of LEDA RFQ [5,6] and our former RFQ shows that 5MHz is enough for the RFQ. There is no special difficulty encountered in our field tuning process, with about one week time, we got the desired field distribution with a flatness of about 2%.

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