STRUCTURE DESIGN OF THE ANNULAR COUPLED STRUCTURE LINAC FOR THE JAERI/KEK JOINT PROJECT

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Abstract

The normal conducting coupled-cavity linac with the Annular Coupled Structure (ACS) is adopted for 190-400 MeV part of high intensity proton linac for the JAERI/KEK Joint Project. The operating frequency is 972 MHz and the 23 modules will be constructed. The basic configuration is based on that investigated for L-band (1296 MHz) in the previous Japan Hadron Project research. However, the structure design is revised and optimized in order to meet requirements of reliability, operation efficiency and cost reduction for the newly proposed Joint Project. As the results of development, the transverse dimensions of the ACS tank are reduced sufficiently with the improvement in RF characteristics. The structure segmentation and essential points of the design are described.

1 INTRODUCTION

As the JAERI/KEK joint project, a high intensity proton accelerator facility will be constructed in Tokai Research Establishment of JAERI [1]. In the linac injector system, an Annular Coupled Structure (ACS) linac accelerates negative hydrogen ion beam from 190.8 MeV to 400 MeV. Also, the same structure is adopted for buncher cavities in MEBT2 placed before the ACS. The operating frequency of them is 972 MHz. The ACS structure was proposed for high-energy proton linac [2], which is a kind of coupled cavity linac. In the cavity, accelerating cells and annular coupling cells are alternately located with cylindrical symmetry and it is operated in $\pi/2$ standing wave mode.

Before the start of this joint project, the ACS was investigated and successfully improved during the KEK Japan Hadron Project (JHP) research [3-7]. Then, the whole system was developed for 1296 MHz and the fabrication program was established through the experimental proof. In the new frequency ACS development, the concept of the JHP-ACS has been introduced as reference and the configurations have been optimized for high-duty factor operation and mass-production. This report presents the structure design of the ACS for 972 MHz.

2 MODULE SYSTEM

An ACS module consists of two ACS tanks, one bridge cavity and two quadruple doublets for transverse beam focusing. The design layout is shown in Figure 1. Each ACS tank contains 15 accelerating cells, 14 coupling cells and two intermediate coupling cells. The bridge cavity has disk-load structure to avoid high-order modes mixing, which contains five exciting cells with movable tuners and four coupling cells. Waveguide is connected at the center exciting cell through an rf window. The inter-tank spacing is 4.5 $\beta\lambda$, where β is the particle velocity scaled by the speed of light and λ is the rf wave length. There are 23 modules in the ACS linac, and the total length is 108.3 m. The main parameters are shown in reference [8].

The ACS cavities are normal conducting type, which are fabricated by stacking and brazing Oxygen-Free-Copper (OFC) segment parts. The ACS tanks are formed with two end segments and many intermediate half-cell segments with a half-accelerating cell and a half-coupling cell. Cooling water channels and vacuum pumping ports are machined into the intermediate half-cell segments. It is shown in Figure 2.

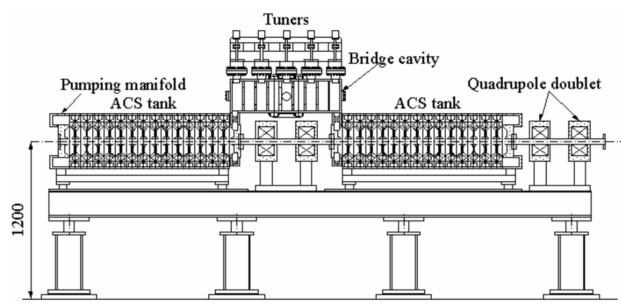

Figure 1 Schematic drawing of the ACS module

3 CAVITY DESIGN

In this joint project, the operating frequency of the ACS is 972 MHz, which is three over four times of one of the JHP-ACS. The particulars of the operating frequency change are described in the reference [9]. The essential design points proved in the JHP-ACS research are the following:

a) Four coupling slots style, to avoid mode mixing problem with high-order modes in coupling cell and to provide more clean axisymmetric accelerating field distribution,
b) Coupling slots with taper edge on coupling cell side, to increase the coupling coefficient and to combine it with structure mechanical strength requirements,
c) Elaborated water circuit scheme for uniform and effective structure cooling,

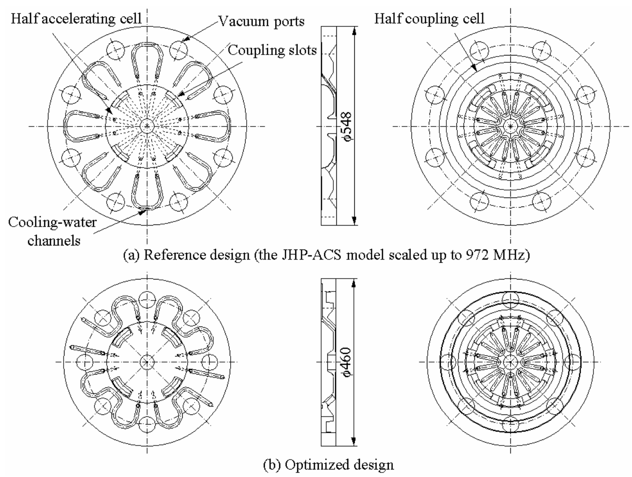

Figure 2 ACS intermediate cell configurations.

d) Multi-cell bridge cavity with movable tuners, to combine two ACS tanks in one Klystron module, avoiding the mode mixing problem and providing possibility of fast and precise frequency tuning.

At first, the JHP-ACS model scaled by operating frequency was adopted as reference of the new structure design for 972 MHz. However, it was mainly optimized to downsize the cavity volume increased by the change of operating frequency and to realize more effective cooling because of high duty factor operation in the future.

The configuration of accelerating cells was optimized to have high shunt impedance value in total energy range, together with reasonable maximal electric field value and careful matching with coupling cells. In addition, the mirror symmetrizing of the coupling slots faced in the accelerating cell is introduced for simplifying the frequency measurement. The details of optimization are described in the reference [10]. The maximal electric field value at the drift tube nose is varied in the maximal field E_{smax}/E_k less than 1.0 as reliable and proof value to ensure the stable operation. Although it is possible to increase E_{smax}/E_k up to 1.3 with the total shunt impedance improvement of 4 %, the practical value is not sufficient for the risk of breakdowns and beam pulse losses in the injecting part of this linac system.

The peripheral part of accelerating cell modified to conical style, instead of initially toroidal, to simplify matching with coupling cell and coupling slots treatment. Although the accelerating cell with a conical part has 3 % lower shunt impedance, the rounding of coupling slot provides more uniform rf current distribution and finally results in higher impedance value and a small coupling coefficient increasing. The dimensions are fixed in the condition that the difference of total shunt impedance is minimal between the constant dimensions and completely variable (from tank to tank, to reach maximal possible impedance value) options. With the fixed dimension, the deviation from maximal possible impedance is less than 2 %.

The most serious revision has been performed for coupling cell design. The shape was changed to reduce the outer diameter and to improve the frequency separation between high-order modes. The coupling cell has the same dimension for all ACS tanks. The pumping ports penetrating the ACS tank are shifted inside coupling cells. As a results, the tank diameter is downsized from 548 mm to 460 mm as shown in Figure 2. The possible increasing of neighbor coupling coefficients was examined and founded in tolerable limits. The electric coupling through the pumping ports just compensates with the initial magnetic coupling from the coupling slots.

With mirror symmetrizing of the coupling slots in accelerating cells and shifting of the pumping ports inside coupling cells, there is no practical distortion of the ACS dispersion curve. The neighbor coupling coefficients slightly improved (to 6 % for 190.8 MeV and 5.5 % for 400 MeV). It is more important for the structure parameters stability. All effects of the field generations in coupling cells; transient effects, beam loading, accelerating cells detuning and multipactoring discharge were examined during the optimization and founded inside safe limits [10].

The bridge cavity connects two ACS cavities with the appropriate inter-tank length and divides rf power fed through waveguide. It consists of five exciting cells and four coupling cells. The center exciting cell has a slot hole to connect waveguide. The cell number was selected to provide the appropriate coupling with the ACS tank [12] and to ensure safe frequency separations between high-order modes. At least, three exciting cells are equipped with movable frequency tuners of a plunger insertion type for fast tuning. Coupling section between the bridge cavity and the ACS end cell is shown in Figure 3. The non-symmetrical intermediate coupling cell and the coupling slot of the ACS end cell were re-designed to provide more controllable and stable coupling value, and uniform rf losses distribution in there. As a result, the rf power loss in the bridge cavity is 4% less than the total one of the ACS module. In order to simplify brazing and tuning procedures for mass-production, the intermediate coupling cell dimensions and outer cell diameter of the bridge cavity are fixed for all ACS modules.

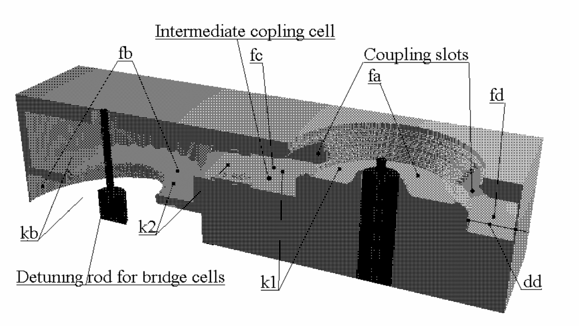

Figure 3 Coupling section between a bridge cavity and an ACS end cell with a intermediate coupling cell.

The cooling structure of each cavity is based on the design of the JHP-ACS with the effective cooling circuit. However, the cooling capacity is improved to realize the good efficiency and uniformity in the operation under high-duty factor. Since the partition between accelerating and coupling cells increases in thickness, the cooling channels placement is more convenient. The simulations for temperature distributions, stress analysis and frequency shift estimations were performed with the ANSYS code. The results show that the new ACS module can operate with the safe cooling water velocity 2 m/sec under maximal 15% duty factor [11]. It signifies the safe module operation for 3% duty factor.

4 CAVITY FABRICATION

The fabrication scheme was established during the JHP-ACS development. The ACS tank and bridge cavity are machined with a super-precision lathe and a milling machine. The process is divided into several steps. An OFC ingot is forged into the required cell profile in a material factory. The forged OFC block is rough-machined to the designed configuration with a margin. After this process, all blocks are annealed in order to remove the residual stresses that would otherwise be released during finish-machining. This process is important for obtaining the accurate finish-machining, and it was also reconfirmed by brazing examination. Then the coupling slots, the water-cooling channel and pumping ports are machined with a milling machine, and each cell is finished with a super-precision lathe. Before the brazing process, the resonant frequencies of each accelerating cell and coupling cell will be tuned within 100 kHz of the designed values. If the measured frequency is over than the acceptable range, the tuning bumps attached in each cell will be cut with a super-precision lathe. The brazing process is divided into three steps. The bridge cavity is brazed with Au-alloy at the first and the second steps. The ACS tank and the bridge cavity are brazed with Ag-alloy at the final step. We carried out the brazing examination with some models and validated that complete annealing process after rough-machining and careful brazing are important. For each process in the fabrication, the optimized ACS design makes more certain advantages because of large reduction of the ACS tank diameter.

5 ACS BUNCHER

Two buncher modules in MEBT2 are ACS type. With the obtained structure design, one module of them has been fabricated as the first high-power ACS module for 972 MHz. In the buncher module, each tank contains five accelerating cells and a bridge cavity has three exciting cells. The inter-tank spacing is 2.5 $\beta\lambda$. Although the machining and brazing examinations of the ACS have been already performed, to apply the final design is the first case. Therefore, it has been carried out carefully and the machining of an OFC model has been started as shown in Figure 4.

Figure 4 OFC model of the ACS buncher.

6 SUMMARY

In the JAERI/KEK joint project, the structure design of the ACS linac has been performed. As the result of parameter optimization, the coupling coefficient and shunt impedance values has been improved in the present ACS design. The important result is reduction of the transverse dimension of the ACS tank. It essentially contributes the cost reduction at all stages of the mass-production; material storage, machining, brazing and rf measuring. With the obtained structure design, the buncher in MEBT2 has been fabricated as the first high-power ACS module for 972 MHz.

7 REFERENCES

[1] F. Natio et. al., in these proceedings.
[2] V. G. Andreev et al., Proc. of 1972 Proton Linac Conference, (1972) 114.
[3] Report of the Design Study on the Proton Linac of the JHP [II], KEK Internal 90-16 (1990).
[4] K. Yamasu et al., Proc. of the 1990 Linac Conference, (1990) 126.
[5] T. Kageyama et al., Proc. of the 1990 International Linac Conference, (1990) 150.
[6] Y. Morozumi et al., Proc. of the 1990 International Linac Conference, (1990) 153.
[7] T. Kageyama et al., Proc. of the 1994 International Linac Conference, (1994) 248.
[8] M. Ikegami et. al., in these proceedings.
[9] JHF Project Office, JHF Accelerator Design Study Report, KEK Report 97-16 (1998).
[10] V. V. Paramonov, The Annular Coupled Structure optimisation for JAERY/KEK Joint Project for High Intensity Proton Accelerators, KEK Report 2001-14 (2001).
[11] S. C. Joshi et.al., in these proceedings.
[12] N. Hayashizaki et.al., in these proceedings.