POWER-HANDLING CAPABILITY OF THE ANNULAR COUPLED STRUCTURE LINAC FOR THE JAERI/KEK JOINT PROJECT

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Abstract

The power-handling capability is the critical issue for a high intensity proton linac of normal-conducting coupled cavity type. In the JAERI/KEK Joint Project a coupled cells linac with the Annular Coupled Structure has been developed in order to operate with 3% duty factor. The ACS accelerating module consists of two ACS tanks and one bridge coupler. The cooling water circuits in the ACS cells ensure the effective and uniform cooling, stabilizing the deviation of cells frequencies. Some of excited cells in the bridge coupler are equipped with fast movable tuners to tune the cavity to the operating frequency. The results of thermal and structural analysis are presented, together with the RF parameter analysis, for different linac regimes. For the adopted ACS module design, the results of the analysis suggest that the operation with the heat loading of up tp 90 kW/m is possible, which is corresponding to the 15% duty factor operation.

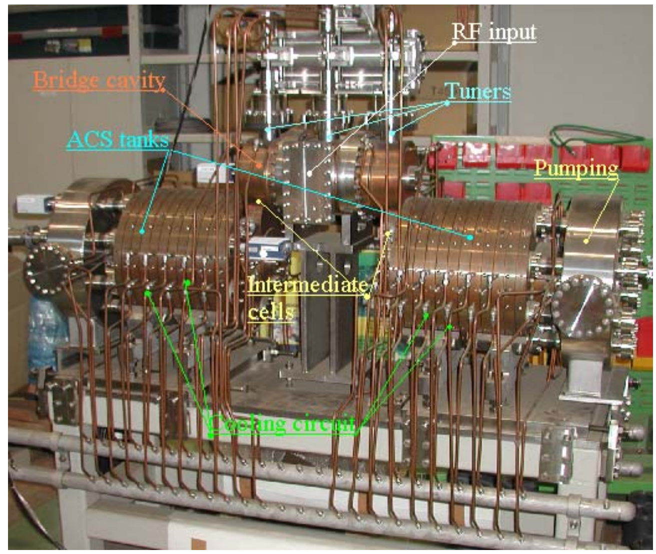

Figure 1. The ACS accelerating module (L-band).

1 INTRODUCTION

For the operating regime of the modern high-intensity hadron linac the normal conducting coupled cells structure operates with a high value of rf power dissipation. This dissipation leads to the non-uniform cells heating, wall deformations, internal stresses generation and frequency shifts. Several coupled solutions - cells shape, cooling circuit, frequency control method compose the cavity concept, determine the tolerable rf power dissipation in the cavity and, finally, the accelerated beam power. In this report the design parameters of the ACS accelerating module for the JAERI/KEK Joint Project linac on power handling capability are described.

2 ACS MODULE CONCEPT

The ACS structure was proposed [1] for high-energy part of proton linacs and improved during the JHP R&D program [2] for applications in intense hadron linac with high duty factor operation. The developed ACS L-band (operating frequency 1296 MHz) module, shown in Fig. 1, was tested at the high rf power level [3], confirming both the cavity concept and realization [4], [5]. For the JAERI/KEK Joint Project linac parameters of the ACS module components are optimized [7] for operating frequency 972 MHz, but the concept and main solutions, proved in the L-band ACS, are conserved.

The ACS accelerating module consists of two ACS tanks. Each ACS tank contains $N_a = 15$ accelerating cells. Option $N_a = 17$, to decrease the number of ACS modules, is under investigation. Through Intermediate Coupling Cells (ICC) the ACS tanks are connected in a resonant cavity with the multi-cell Bridge Coupler (BC) [6]. The BC operates in $\pi/2$ mode and several excited cells (at least 3) are equipped with fast precise movable tuners for the module frequency control. To decrease additional rf power dissipation in BC, non-symmetrical coupling is realized between BC - ICC (coupling coefficient k_2) and ICC - ACS tank (coupling coefficient k_1). In the ACS accelerating module the functions of the structure cooling and frequency control are separated.

3 ACS TANKS COOLING

To provide effective and uniform cooling of the ACS cells, the cooling circuit scheme was developed in the L-band ACS [5] and with minor changes, due to mirror symmetry of coupling slot positions, is adopted for the present design (see Fig. 2). Cooling channels, placed both in the webs between accelerating cells and in the mid-planes of accelerating cells (between coupling cells) connected with inter-conecting channels, placed between accelerating and coupling cells. Each cooling loop serves for one mid-plane and two webs. The mid-plane has two cooling circuits, the web has four.

The coupled analysis of the ACS cells has been performed following the procedure described in [8]. The conserva-

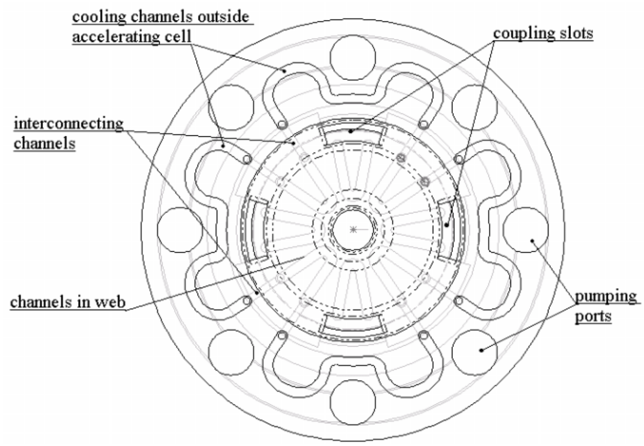

Figure 2. The cooling circuit for the ACS structure.

Table 1. Results of the structural analysis for ACS cells.

β	P_l	δT_{max}	δP_T	δf_a	δf_c
	$\frac{kW}{m}$	C^o	%	kHz	kHz
0.5581	15.5	4.4	0.5	-42.2	2.72
0.5581	77.5	22.9	2.4	-211.0	13.6
0.7115	12.2	4.2	0.5	-35.6	-2.6
0.7115	60.8	22.3	2.4	-178.0	-13.0

tive value for the cooling flow velocity $\leq 2\frac{m}{sec}$ is foreseen, corresponding to the film coefficient value $\approx 9530\frac{W}{m^2 C^o}$. The average rf power dissipation $20kW$ per ACS tank, with reasonable safety limits corresponded [9] to 3% duty factor linac operation, and $100kW$ were considered for 15% duty factor. Results of analysis are summarized in Table 1, where P_l is the power dissipation per unit length, δT_{max} is the maximal temperature difference between cooling water and cells surface, δP_T is the rf power dissipation increasing due cell surface heating [8], $\delta f_a, \delta f_c$ are frequency shifts of accelerating and coupling cells, respectively. The typical temperature distribution in the ACS cells is shown in Fig. 3 for 15% duty factor scenario. The maximal stress value was founded [10] very close to the yield stress even for 15% duty factor operation scenario.

The cooling capability of the ACS tanks increases with β decreasing - the number of cooling circuits per unit length increases. For lower $\beta \sim 0.43$ (proton energy $\approx 100MeV$) the higher heat loading P_l is possible and $P_l \approx 90\frac{kW}{m}$ provides stresses inside elastic limit, together with tolerable δT_{max} value.

4 BRIDGE CAVITY

Nine cell ($N_b = 9$) cavity is adopted [7] for the BC, with 5 excited cells, respectively. The "constant volume cells" concept is realized in the BC for present design together with new ICC shape [7] to ensure constant BC parameters for all β and more uniform rf losses distribution in adjacent ACS accelerating cell.

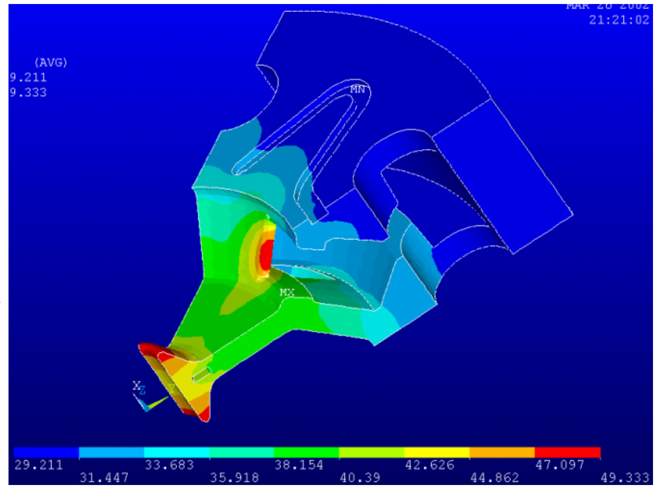

Figure 3. The temperature distribution in the ACS structure for 15% duty factor, $\beta = 0.56$.

The BC influence on ACS module parameters strongly depends on k_2/k_1 ratio. 3D MAFIA simulations showed the ratio $\frac{k_2}{k_1} \leq 4$ as a possible value. Increasing of k_2 coupling coefficient leads to the field decreasing in BC cells. It may lead to problem during matching with the driving waveguide and increases tuning errors for ICC. As the result of consideration and compromise the ratio $\frac{k_2}{k_1} = 2$, tested in experiments [3], [6], is chosen for realization.

Additional rf power dissipation P_{bt} in the BC is estimated as:

$$P_{bt} = \frac{5P_aQ_a}{2N_aQ_b}(\frac{k_1}{k_2})^2 \approx 0.04P_a, Q_b \approx 1.2Q_a, k_2 = 2k_1$$

where P_a is the rf power dissipated in two ACS tanks. At least 3 excited BC cells are equipped with movable tuners. Supposing the tuner dimensions scaled from tuners in the L-band module, the tuning rate for the single BC cell, according MAFIA simulations, is $\frac{\partial f_b}{\partial l} \approx 700\frac{kHz}{mm}$. For the ACS module operating frequency (assuming 3 tuners simultaneous moving) the tuning rate

$$(\frac{\partial f}{\partial l})_{ACS} = \frac{3(\frac{k_1}{k_2})^2}{5(\frac{k_1}{k_2})^2 + 2N_a}(\frac{\partial f_b}{\partial l}) \approx 16\frac{kHz}{mm}$$

is reasonably soft and effective.

5 HIGH RF POWER OPERATION

If accelerating cells of the coupled cell structure are regularly detuned for δf_a value with respect operating frequency f_0, it leads to the coupling cells excitation. Relative coupling cell excitation X_{cn} linearly rises from the ACS tanks ends ($n = 1$) to the BC ($n = N_a - 1$):

$$|X_{cn}| = |X_a|\frac{2n\delta f_a}{k_{ac}f_0}.$$

where X_a is the field in accelerating cells, k_{ac} is the coupling coefficient of the ACS cells. The large field value

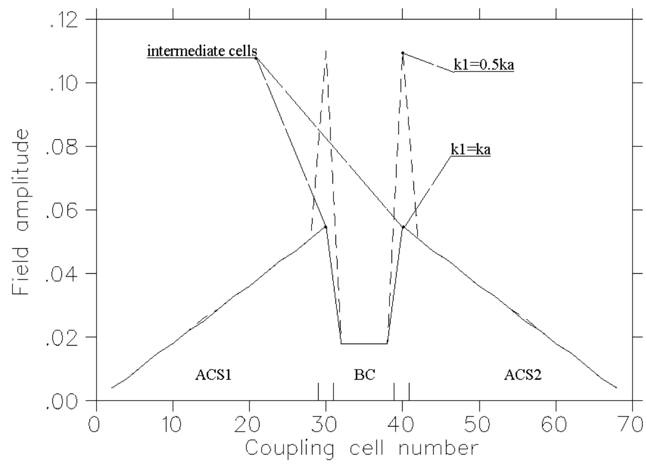

Figure 4. The field distribution in coupling cells along the ACS module for the detuned accelerating cells. $k_{ac} = 6\%, \delta f_a = 100kHz, N_a = 15$.

generates in the ICC ($n = N_a$):

$$|X_{cN_a}| = |X_a| \frac{2\delta f_a}{k_1 f_0} + |X_a| \frac{k_{ac}}{k_1} \frac{2(N_a - 1)\delta f_a}{k_1 f_0}.$$

The possible field distributions in coupling cells are shown in Fig. 4. To avoid the field enhancement in the ICC, the ICC-ACS coupling should be not less than ACS cells coupling - $k_1 \geq k_{ac}$. The coupling cells excitations leads to additional rf power losses P_{cc} in all coupling cells:

$$P_{cc} \approx \frac{2N_a^2 + 3N_a}{3} \frac{P_a Q_a}{Q_c} (\frac{2\delta f_a}{k_{ac} f_0})^2.$$

The detuned cell mode will be all time in the ACS cavity operation - either short time at the start of rf power input or long time during operation. The ACS coupling cells were examined [7] for possible sequences of cells excitations (electrical breakdown, multipactor discharge, additional rf losses) and no danger was founded, it is more safe to have tuned accelerating cells during operation. It is foreseen in the procedure of the ACS accelerating cells tuning - the cold cells tuned for higher frequency $f_0 + \delta f_a$ and the module operating frequency maintained with tuners withdrawn with respect operating position.

As one can conclude from the results presented, the ACS accelerating module has the large reserve for 3% duty factor linac operation. The temperature difference at the cells surface (see Table 1, Fig. 3) is smaller as compared to another structures, internal stress value is match lower than elastic limit, the coupling cell frequency change is practically zero. With the tuners range $\geq 30mm$ the compensation of accelerating cells frequency change $\delta f_a \sim 40kHz$ is also not a problem $\delta l \approx 3mm$.

Moreover, in the present design tuned for 3% duty factor linac operation, the ACS accelerating module has the possibility to operate with 15% duty factor. Then the additional frequency shift for accelerating cells $\delta f_a \approx 170kHz$ also can be compensated by the same tuners. Practically there will be now stop band opening - possible frequency shift for coupling cells $\delta f_c \approx 10kHz$ is inside tuning tolerance. Internal stresses are expected near yield stress - it may be a point of attentions. The maximal coupling cell excitation in the ICC $X_{cN_a} \approx 0.09X_a$ looks also safe against sparking and muplipuctoring. Additional rf losses $\delta P_T + P_{cc}$ are expected in tolerable limits ($\delta P_T \approx 2.4\% P_a, P_{cc} \approx 1.1\% P_a$).

6 CONCLUSION

During previous the JHP R&D program the robust concept of the ACS accelerating module was developed and tested - reasonably effective accelerating structure with effective cooling circuit, added with bridge coupling cavities, equipped with fast movable tuners. Together with the latest improvements and following to the concept of the total cavity, ACS module looks now as the very promising cost-effective solution for normal conducting high intensity proton linac with high duty factor operation. The present ACS 972 MHz module for the JAERI/KEK Joint Project linac has the large reserve for safe operation with 3% linac duty factor and without additional tuning may serve for 15% duty factor linac operation.

7 ACKNOWLEDGMENTS

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