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THE RESONANCE FREQUENCY SHIFT AFTER APPLYING THE COOLING SYSTEM FOR A SIDE COUPLED STANDING WAVE LINAC

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Abstract

A radio frequency accelerator tube used in linear medical accelerators includes three main sections of the radio frequency cavity, an electron gun and the X-ray target, which is vacuumed by a pump inside it. The electromagnetic energy loss in the structure of the cavity can increase the temperature of the tube, resulting in changes in the geometric dimensions and then changes in some of the cavity characteristics, such as the resonance frequency. A cooling system is required to prevent excessive change in the resonant frequency due to thermal loss. Also, it is necessary to perform some computer simulations to stabilize the cavity's performance in the presence of electromagnetic energy thermal dissipation and the cooling system. In this paper, the simulation results of resonant frequency shifts after applying the cooling system have been reported.

INTRODUCTION

As we know, in terms of the accelerating structure, essentially electron linear accelerators are divided into traveling wave and standing wave structures. The design and construction of standing wave cavities are more complicated than standing wave cavities. On the other hand, the stability of the cavity's performance plays an important role in the characteristics of the outlet beam. In medical applications, the stability of cavities is more important [1]. By changing the nominal frequency of the cavity, the impedance matching of the transmission line and the accelerating cavity are changed and a large part of the power is reflected. Due to the high quality factor of standing wave cavities (about 17000), and 1.23 coupling constant, the cavity bandwidth (FWHM) will be about 400 kHz. It means that, by varying the frequency of 200 kHz, the input power to the cavity will halved and the output energy will be 4.28 MeV instead of 6MeV. The acceptable frequency shift of the cavity applied by using the cooling system, depends on the ability of the automatic frequency control system (AFC) [2]. The operation of the automatic frequency control system is determined by the two factors of the linear behavior and the response rate of the system relative to the radiofrequency pulse repetition rate [3, 4]. In the conventional analog frequency regulator system used in medical linear accelerators, the frequency correcting range in about 0.9 MHz with 300 pulse per second repetition rate. Therefore, the maximum frequency shift of the cavity after applying the water cooling system should not exceed 450 kHz. That can be easily stabilized by the automatic frequency control system [3].

GEOMETRY AND COOLING SYSTEM DESIGN

The geometrical parameters of RF cavity were optimized for operation in 2998.5 MHz in coupled cells configuration. The cavity will be operated with 2.6 MW input power with 5 μs beam length and 150, 200 and 300 Hz repetition rate. The loss of each accelerating cell will be calculated for mentioned repetition rate equal to 250, 350 and 500 watts for each accelerating cell for beam current of 100 mA by dividing to number of accelerating cells respectively. For this cavity, three types of cooling systems were investigated. The first type is the cooling system with tangential circular cross section, the second type is the cooling system with tangential rectangular cross section, and the third type is internal cooling system with circular cross-section. The inner diameter of the circular cross-section pipes is 8mm and the internal dimensions for the rectangular cross-section is 7mm*5mm. The inlet water velocity and temperature for all three types is 2m/s and 20, 22, 25°C respectively. The thermal calculations and total deformation of the cavities after applying of the cooling system have been reported in another paper [5]. Figure 1 illustrates the cooling system designs and Table 1 shows the temperature comparison for them.

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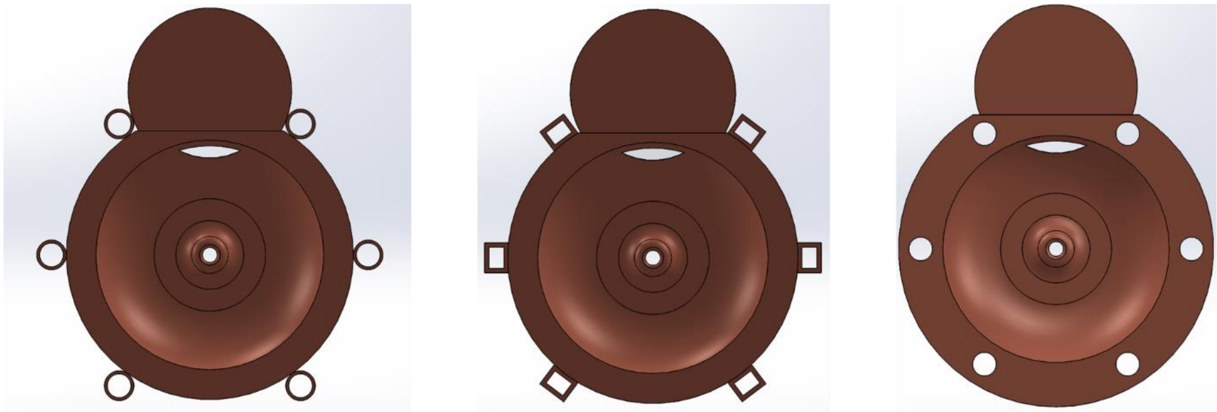

(a) (b) (c)

Figure 1: Cooling System Designs.
a) Tangential Pipe. b) Tangential Duct. c) Internal Pipe.

Table 1: Comparison of Cooling Systems for 250, 350 and 500W Power Loss

Power Loss (W)	Cooling Water Temp. (°C)	Pipe		Duct		Internal Pipe	
		Temperature (°C)		Temperature (°C)		Temperature (°C)	
		Min.	Max.	Min.	Max.	Min.	Max.
500	20	25.603	55.208	27.66	49.592	28.628	45.86
	22	27.6	57.2	29.656	51.586	30.622	47.855
	25	30.595	60.187	32.65	54.576	33.614	50.849
350	20	23.923	44.648	25.363	40.716	26.041	38.103
	22	25.92	46.64	27.359	42.71	28.036	40.099
	25	28.915	49.627	30.353	45.701	31.028	43.093
250	20	22.803	37.608	23.832	34.799	24.317	32.932
	22	24.8	39.6	25.828	36.793	26.311	34.928
	25	27.795	42.587	28.822	39.783	29.303	37.922

FREQUENCY SHIFT

To obtain the resonant frequency shift after the deformation caused by the stresses introduced into the cavity, HFSS coupling with Steady-State Thermal and Static Structural were used in Ansys workbench[6]. After obtaining the initial resonance frequency and the power loss, the geometry was transferred to the Steady-State Thermal with its power loss. After thermal analysis and transferring the temperature distribution to the Static Structural as a load, the geometry of the deformed cavity was obtained. By resetting the deformed geometry to HFSS, the resonant frequency of the deformed cavity was obtained. The configuration of this multi-physics analysis at the ansys workbench in shown in Figure 2. The frequency shift for all three types of cooling system is shown in Table 2 for comparison.

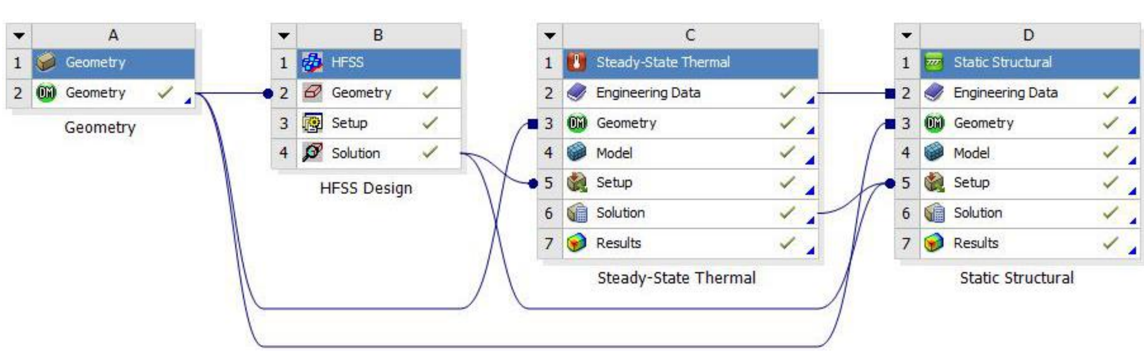

Figure 2: RF-Thermal-Structural-RF Coupling analysis in Ansys Workbench.

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Table 2: The Obtained Frequency Shift for the Different Conditions of Cooling Systems

Power Loss (W)	Cooling Water Temp. (°C)	Pipe Frequency (MHz)	Duct Frequency (MHz)	Internal Pipe Frequency (MHz)
500	20	0.35	0.30	0.19
	22	0.39	0.34	0.21
	25	0.45	0.39	0.24
350	20	0.16	0.19	0.13
	22	0.19	0.22	0.15
	25	0.25	0.28	0.18
250	20	0.15	0.13	0.08
	22	0.17	0.17	0.10
	25	0.21	0.22	0.13

CONCLUSION

The lowest frequency variation for the internal cooling system with circular cross section with a dissipation power of 250W and an inlet water temperature of 20 °C was 0.08 MHz and the highest frequency variation for a tangential cooling system with circular cross section with a power loss of 500 W and an input water temperature 25 °C was 0.45 MHz Due to the automatic frequency control (AFC) used in linear medical accelerators, and their frequency range (about 0.9 MHz), designed cooling systems have a good performance.

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