Design study on very low Beta spoke cavity for China-ADS[*]

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Abstract: Very low Beta superconducting spoke cavity is one of the key challenges for the China-ADS project. In this paper, a new structure of $3\beta\lambda/2$ spoke cavity is first studied in detail. Its RF and mechanical properties are simulated using CST-MWS and ANSYS, and compared with the traditional $\beta\lambda/2$ spoke structure.

Key words: low Beta spoke cavity, $3\beta\lambda/2$ spoke cavity, CST-MWS

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1   Introduction

Spoke cavity is a TEM-class and generally superconducting resonator. In addition to the inherent advantages of superconductors, the spoke cavity has a more compact structure with the same frequency than the elliptical cavity, and higher shunt impedance than the half-wave resonator, etc [1]. Therefore, many large-scale accelerators, which need high power and high intensity protons, have been proposed to adopt spoke cavities, and the China-ADS linac is one of them [2–4].

Figure 1 is the layout of the China-ADS linac with the scheme of Injector-I [4]. The proton beam originates from an ECR ion source, and is then accelerated to 3.2 MeV by a CW normal conducting RFQ. From 3.2 MeV to 178MeV, the beam is accelerated by three different types of superconducting spoke cavities (Spoke012, Spoke021, Spoke040). After that, the

beam is accelerated by two types of superconducting elliptical cavities.

Among the three spoke cavities, Spoke012 is believed to be the most challenging one since it is of very low geometrical Beta, which is only 0.12. Lower Beta means a thinner cavity and thus smaller areas of high magnetic fields, and therefore presents naturally larger values of $\mathrm{d}f/\mathrm{d}P$. In other words, the mechanical stability of low Beta spoke cavity against helium pressure fluctuations is inherently poor [5].

In order to improve $\mathrm{d}f/\mathrm{d}P$ for a very low Beta spoke cavity, the typical approach is to develop sophisticated stiffening ribs, but it will not be discussed here. In this paper, we will investigate a new structure, whose length from gap-center to gap-center, $L_{\text{g-g}}$, is $3\beta\lambda/2$, instead of the traditional value of $\beta\lambda/2$, as illustrated in Fig. 2. This new structure has a different electric field pattern from the traditional one, as compared in Fig. 3.
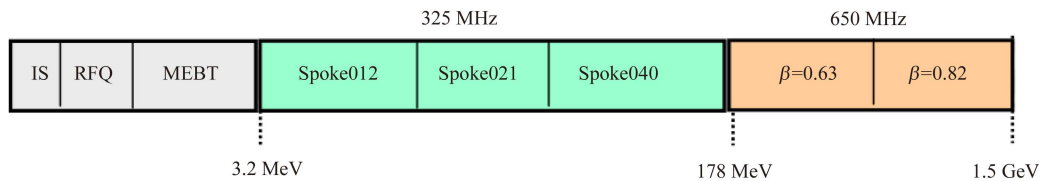

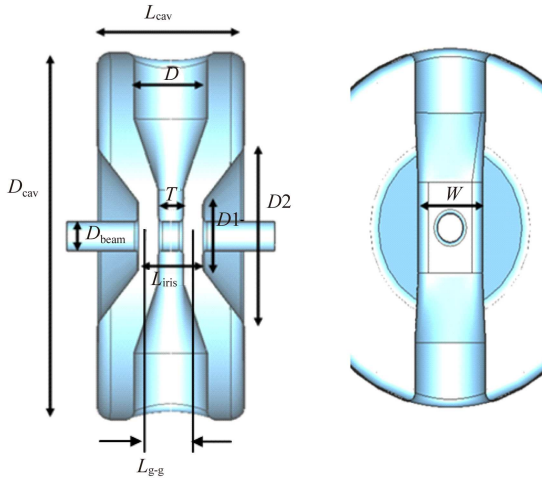Fig. 1.   Layout of China-ADS linac with Injector-I.

Fig. 2. The cross section of a spoke cavity with the main geometric parameters: L_{cav}-cavity length, L_{iris}-iris to iris length, W-spoke width, T-spoke thickness, D_{cav}-cavity diameter, D-spoke diameter at base, $L_{g\text{-}g}$-length from gap-center to gap- center.
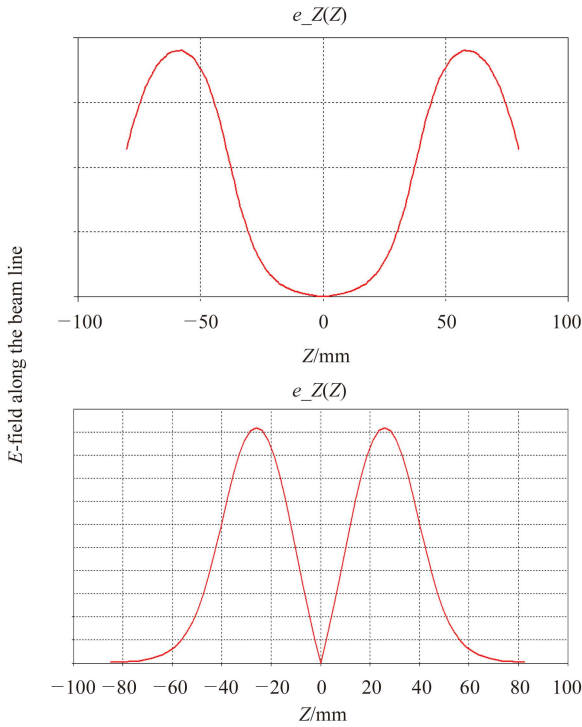

Fig. 3. Different E pattern for the traditional $\beta\lambda/2$ structure (bottom) and the $3\beta\lambda/2$ one (upper).

Led by the beam dynamics considerations, two different low Beta spoke cavities which may accelerate the 3.2 MeV proton beam are chosen to be design-studied. One is the traditional Spoke012, and the other is the $3\beta\lambda/2$ spoke cavity, Spoke009T.

2 RF optimization of Spoke012 and Spoke009T

The RF design and optimization were done using Microwave Studio (MWS) software [6].

For a spoke cavity, several parameters may typically be optimized, such as the spoke shape, spoke width-W, the gap ratio T/L_{iris} and ratio D/L_{cav} [7, 8]. As an example, Table 1 and Fig. 4 show the optimization of the spoke shape for the traditional spoke012 cavity.

Table 1. RF parameters for different spoke shapes.

spoke shape	round	elliptical	racetrack
G/Ω	51	53	70
$(R/Q_0)/\Omega$	124	135	93
E_{peak}/E_{acc}[1]	3.4	3.2	3.7
B_{peak}/E_{acc}[1] (mT/(MV/m))	5.1	4.6	4.4

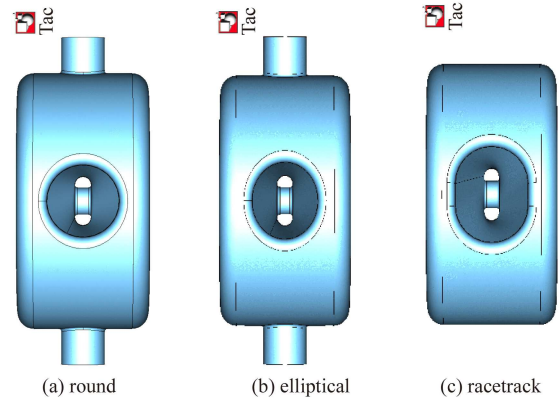1 E_{acc} is the total accelerating voltage divided by L_{iris}.

Fig. 4. Three spoke shapes.

Table 1 indicates that the elliptical spoke shape has better RF properties: lower peak fields and higher R/Q. So we chose this shape for Spoke012.

For the new structure, Spoke009T, besides the above parameters, we have also investigated the influence of the effective cavity length (L_{iris}) while keeping $L_{g\text{-}g}$ constant, $L_{g\text{-}g}$ = $3\beta\lambda/2$= $3\times0.087\times923/2$=120 mm.

From Fig. 5, B_p/E_{acc}, E_p/E_{acc} and G increase greatly with L_{iris} after 160 mm , while R/Q decreases with L_{iris}. So 160 mm is adopted for the L_{iris} for a trade-off.

As a preliminary optimization result, the geometric parameters of Spoke012 and Spoke009T are confirmed and listed in Table 2.
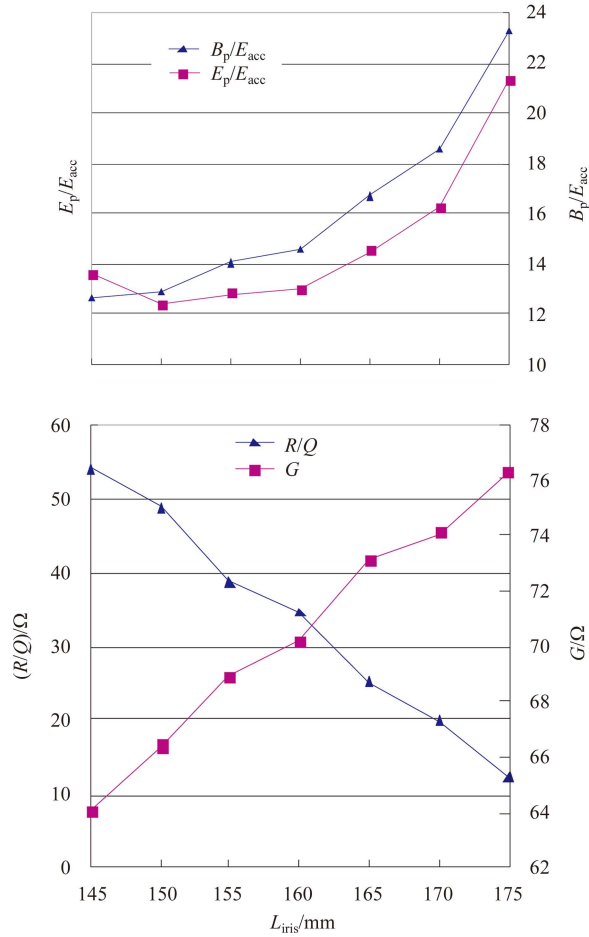
Fig. 5. B_p/E_{acc}, E_p/E_{acc}, R/Q and G vs. L_{iris} for Spoke009T.

Table 2. Geometric parameters of Spoke012 and Spoke009T.

	L_{cav}/mm	L_{iris}/mm	T/mm	W/mm
Spoke012	170	74	29	89
Spoke009T	260	160	80	120
	D_{cav}/mm	D_1/mm	D_2/mm	
Spoke012	438	81	219	
Spoke009T	476	120	288	

3   Comparisons between Spoke012 and Spoke009T

The comparison of RF properties is shown in Fig. 6 and Table 3.

Table 3. RF parameters of Spoke012 and Spoke009T.

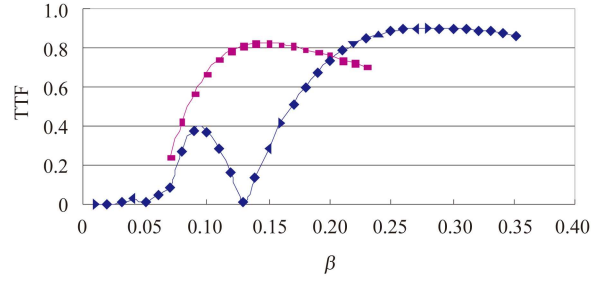|	f/MHz	$(R/Q)/\Omega$@βg	E_p/E_{acc}
Spoke012	325	135	3.2
Spoke009T	325	35	9.3
	$(B_p/E_{acc})/$ (mT/MV/m)	G/Ω	TTF
Spoke012	4.6	53	0.77
Spoke009T	14.6	70	0.4

Fig. 6. Transit time factor (TTF) at different β for Spoke012 (rectangle) and Spoke009T (triangle).

The mechanical properties of the two cavities without ribs have been simulated using ANSYS code [9], and the results are shown in Fig. 7 and Table 4.
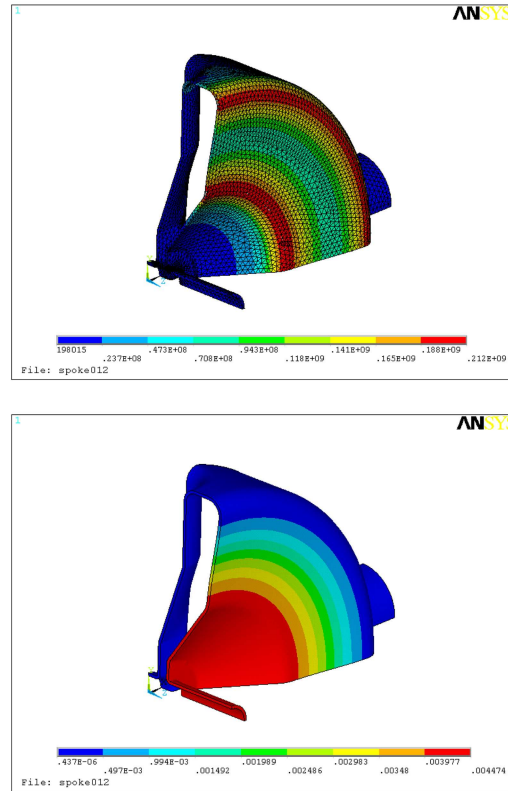

Fig. 7. Simulation of stress (upper) and displacement (bottom) for Spoke012 at 1atm.

Table 4. Mechanical parameters of Spoke012 and Spoke009T.

	Spoke012	Spoke009T
df/dP/(kHz/Torr)	18	6.8
Freq. sensitivity for tuning/(kHz/mm)	1319	620
displacement sensitivity for tuning/(mm/980N)	0.58	0.44
peak displacement under 1atm with pipe free/mm	4.5	3.6

From the above analysis, it is found that compared with spoke012, spoke009T has a thicker shell and about 3 times smaller $\mathrm{d}f/\mathrm{d}P$, but lower TTF for the low energy proton beam whose β is about 0.1. And, as known, for the same accelerating voltage, lower transit time factor will induce higher peak field and larger cryogenic load.

4   Conclusion

Very low Beta spoke cavity is one of the key challenges for the China-ADS linac, and it has no precedent in the world. Since the traditional structure for very low Beta spoke cavity has quite poor mechanical stability, a new $3\beta\lambda/2$ structure has been studied. The preliminary design study shows that the new structure can significantly improve and enhance the mechanical properties of the cavity, but at the expense of poorer RF parameters. Next, we will optimize these two structures further and develop the Spoke012 prototype first.

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