A POSSIBLE CONCEPT TO IMPROVE THE EFFICIENCY OF THE VERY LOW BETA SC ACCELERATING STRUCTURE

YANG Liu, LU Xiang-Yang[#],

State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China

Abstract

This paper introduce a possible solution to improve the efficiency of the very low beta SC accelerating structure, via extending the gaps number of 4-gap interdigital QWR by doubling its stems number. The new cavity is a 8-gap QWR, which is comprised of two parallel TEM resonant lines operating in opposing phase from each other. It maintains the 4-gap QWR's good EM parameters and enables the use of demountable flange. The more important advantage is the potential improvement of efficiency. According to a preliminary estimation of longitudinal dynamics, the 8-gap QWR could stably accelerate heavy ion at the velocities 0.01<v/c<0.05.

INTRODUCTION

In many cases, the RF linac efficiency can be significantly increased by using multi-cell cavities [1]. The high energy gain per cavity leads to a sufficient decrease to cavity number with their RF systems and control systems. For a superconducting beam line, If the focusing elements are operated at room temperature, using multi-cell cavities makes an additional effort in a high number of separated cryostats accompanied by many cold-warm transitions. As for the low beta case, a lot kinds of cavities with different geometries, beta, and frequencies have been developed for so long, but most of them are limited by the accelerating cells number. Applying the EQUUS concept (equidistant multi-gap structure), the superconducting CH-type cavity with more than 15 gaps has been extended to the beta<0.1 region [2], which would have a significant benefit on the related proposed projects, particularly for their post-accelerators. In case of very low beta section with beam energy below 1Mev/u, the CH type cavity probably doesn't fit well due to its limited transverse diameter. However, the 4-gap interdigital QWR, was proposed by L. M. Bollinger [3], especially the optimized version well known for its low surface peak field, high flexibility in beam energies and charge-to-mass ratios of the beam particles, is a quite competitive candidate for the velocities 0.008<v/c<0.05 [4]. If we replace the 'fork' stem in a 4-gap QWR by two of it, the gaps number would be doubled accompanying with a narrower velocity acceptance and less charge-to-mass ratio flexibility. The previous π mode is divided into two degeneracy modes. This seems not to be attractive. But if the higher π mode was chosen-the two parallel TEM resonant lines operating in opposing phase from

each other, where most surface current oscillating between them, the use of demountable flange would be enabled. A demountable flange opens an access into cavity interior, so it makes a cavity easier for surface treatment and be much more possible to reach a higher gradient[5]. In the following sections, a possible concept, which involves the multi-cell efficiency, the 4-gap QWR good EM parameters, and the movable flange characteristic, referring to a 8-gap QWR, will be introduced in more details.

RF GEOMETRY

As aforementioned, based on the 4-gap type QWR, the gaps number is extended by doubling the stems number. The π mode is chosen as the demountable flange characteristic is preferred. To resonantly accelerate beam, an extra drift tube with length βλ/2 is inserted in the middle gap. Figure 1 shows the evolution from 4-gap QWR to 8-gap QWR (sketched in cut view containing beam line and with schematic electric-field pattern). The latter cavity tank is in hexahedron shape instead of cylinder. Since the added drift tube causes the two stems are apart far from each other, the magnetic coupling between them would be much weaker, which means the coupling inductance in the shorting region can't collect substantial portion of the surface current while the rest would flow into the outer wall. If the cylinder tank was used, there would be no place in the cavity to put a large size flange. Responding to hexahedron shape, the fields are concentrated in the outer plates perpendicular to the x and y axes, and vanishing toward the z direction. To minimize the current flow on the surfaces perpendicular to the z axes, these horizontal cross bars should be in the same orientation with the stems, and meanwhile meet the bottom plate. As a consequence, the main current flow would circulate several closed loops (displacement current longitudinally along gap) in the x-y plane, and less current could pass through the joint on the two
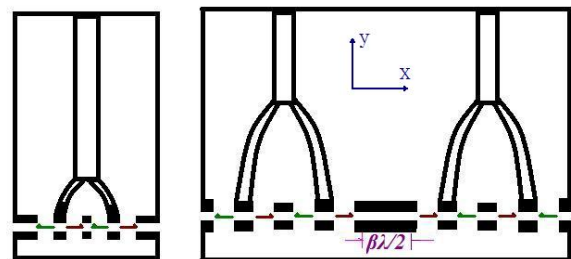

Figure 1: 4-gap QWR (left), 8-gap QWR (right).

parallel plates. To check this property, a 8-gap beta=0.025 QWR was built and simulated with the code CST Microwave Studio. Figure 2 illustrates its cut-view and surface current distribution. The concerned surface current in the joint region is approximately 2 mT at Bp=40 mT, which is low enough and acceptable. Therefore, the two plates paralleling with the main current loops can be demountable. If we cut gaps number off to three like the interdigital two stubs QWR [5], the velocity and charge-to-mass ratios acceptance of beam particles can be wider, and the demountable feature is maintained as well. In terms of very low beta range, typically beta=0.03, since the stub diameter is limited by the short gap length, the surface current distributing on it should be quite large as Ampere's law presents. As a result, an unacceptable surface peak magnetic field would be generated at somewhere. As for 8-gap QWR, the situation is inverse-the sufficient gaps number between two inner stems provides enough space to enlarge their diameters even if the gaps length probably is rather small. Therefore, this type of QWR could inherit the 4-gap QWR's good EM parameters with a promising potential.
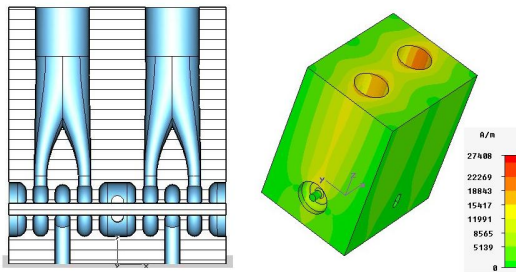

Figure 2: cut view and surface current distribution of a 8-gap QWR with beta=0.025.

PARTICLE DYNAMICS

Referring to low constant beta accelerating structures, the effect of phase sliding is unavoidable, particularly for the velocities v/c<0.05. To figure out a desirable longitudinal motion for an equidistant 8-gap low beta QWR, the EQUUS concept (equidistant multigap structure) successfully applied in CH type cavity is quoted [2]. The stand wave along beam line can be represented as a superposition of the forward and the backward travelling waves. The accelerated bunch enters the cavity with negative phase against to the forward travelling wave. Since the bunch is initially slower than the wave, its center slides to the wave crest and reaches the maximum phase at the middle of the cavity. Afterward, it is faster than the wave and moves back to negative phase. When all the related parameters are properly set, the above process is practical and the bunch acceleration is under control.

The charge-to-mass ratio acceptance, determining the particles fitting for accelerating, is also concerned,

therefore, this paper gives a preliminary estimation for the 8-gap type QWR. Taking beta=0.03 as example, the frequency is at a typical value 100MHz. This information determines the cell length $\beta\lambda/2$ -around 45mm, which is a reasonable value [1]. The forward wave magnitude E0 is assigned 10MV/m. It seems like a little bit impractical, however, current state of the art TEM-class SC cavities, provides substantially high gradient [6], and higher E0 fits the conservation of beam simulation. The related formulas are listed:

$$\Delta\phi_c = -2\sqrt{\frac{\pi mc^2 \beta s}{eq \cdot E_0 \lambda}} \cdot \int_{\psi 0}^{\psi m} \frac{d\psi}{\sqrt{\sin(\psi) - \sin(\psi m)}},$$

$$N_g = \frac{\Delta\phi_c}{\pi} + 1,$$

where eq/m is charge-to-mass ratio; βs is synchronous velocity; the integral variable ψ represents the phase shift between non-synchronous and synchronous particles; ψ_0 determines the RF phase of the bunch center when crossing the first and the last gap centers, while ψ_m is the maximum phase, reached by the particle as its velocity exactly equals to the phase velocity of the structure. The first formula evaluates the total RF phase change between the first and the last gap of the cavity, and the latter one calculates the valid gaps number at the specific parameters. Assuming $\psi_m = 0$ and $\psi_0 = -50°$, a curve related to gaps number Ng versus charge-to-mass ratio acceptance is drawn in Figure 3.
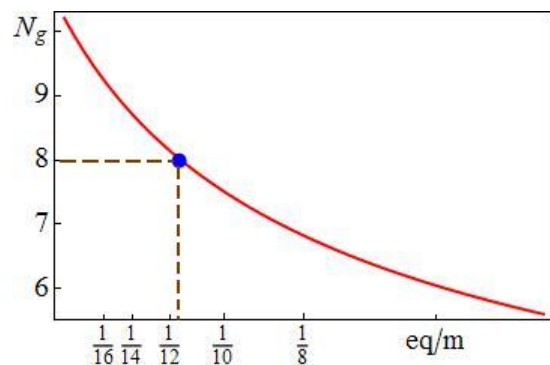

Figure 3: gaps number Ng versus charge-to-mass ratio acceptance.

As the figure shows, if eq/m is lower than 1/12, the associated particles could be accelerated stably for this kind of 8-gap QWR.

Very low charge state beams, however, requires strong transverse focusing [7][8], especially for very low velocity. The linac FODO lattice consisting of a SC quadrupole following each 8-gap QWR probably fulfills the strong transverse focusing. In terms of beam simulation, the particle phase should be associated with the assumed accelerating field. All the simulations including electromagnetic design and particle tracking

can be performed by the widely used codes, when a prototype has been studied out. If wider charge-to-mass ratio acceptance is preferred, the electronic field magnitude E0 should be reduced. This is not advisable. Note that the particles valid for 4-gap QWR almost include proton, if a 8-gap QWR is consisted of two different beta sections while each section includes four gaps, what would happen? When a non-synchronous particle passes though the entire cavity, its phase motion will cover two cycles, as it is accelerated by two 4-gap QWRs. As a result, a higher flexibility for charge-to-mass ratio will be obtained. But the associated problems, such as the match of the two beta sections, the beta difference between the two sections, and the narrower velocity acceptance, however, can't be ignored and should be investigated deeply.

DISCUSSION AND CONCLUSIONS

The 8-gap quarter-wave superconducting cavity is a possible solution providing effective and efficient means of accelerating ion beams in the velocity range from 0.01 to 0.05. It is greatly potential to minimize the surface peak fields, at the same time, its movable flange characteristic allows an easy access to the interior of the resonator for manufacture, inspection, mechanical polishing, chemical surface treatment, high pressure rinsing, coating, and repair. Apparently, this is significantly beneficial to improve the real gradient. Applying the EQUUS concept, a 8-gap beta=0.03 QWR can stably accelerate these low charge state beams typically below 1/12. Wider charge-to-mass ratio acceptance can be obtained by dividing a 8-gap QWR into 2 different beta sections consistent with a narrower velocity acceptance. How to balance this trade-off, however, depends on the application. The transverse beam dynamics simulation is still open, which combing with cavity design will be the next section work.

ACKNOWLEDGEMENTS

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