SUPERCONDUCTING ACCELERATING STRUCTURE WITH GRADIENT AS 2 TIMES HIGHER AS TESLA STRUCTURE

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Abstract

A proposed new accelerating structure for TESLA is assumed to have an effective gradient 2 times more than existing 9-cell cavity [1]. This structure is an interlaced combination of two side-cavity-coupled standing wave substructures with λ/4 cells length. Intercell coupling provides side-coupled cavities, which are made from a special shape waveguide section. The high accelerating gradient is accomplish by 4 factors:

1) The shortened accelerating cells have transit time factor 0.9 instead of 0.64 for conventional standing wave cells with λ/2 length.

2) The side magnetic coupling has made it possible to reduce the cells beam aperture that reduce relation between the maximum surface field and the acceleration gradient.

3) Stronger intercell coupling allows extending the accelerating cavity and improving a duty factor of linac.

4) Availability of the side coupling elements enables to use them for power input and HOM-couplers. It reduces intercavity distance and enhances duty factor too.

INTRODUCTION

Under development of a superconducting linear accelerator the greatest efforts are applying to increase its effective accelerating gradient. The next significant parameter is shunt impedance. But shunt impedance of a superconducting linac is higher than 5-6 orders of magnitude for "warm" accelerators and is not so important to choice of a geometry superconducting linac. A few methods for improvement of acc. gradient are known. They are including an application of shortened cells for accelerating structure, reducing linac aperture and increasing of active length of accelerators by shortening of inter-cavity spacing. The first two methods increase acc. gradient due to reducing surface electric and magnetic fields into an accelerating cell. And third method extends effective length of accelerator. In this report a novel type of standing wave accelerating structure, which combines all these methods, is suggested.

DOUBLE-CHAIN BIPERIODIC STANDING WAVE STRUCTURE

Experience of employment of biperiodic accelerating structures with side coupled resonators (see Fig.1) showed their high efficiency in comparison with ordinary iris-loaded cavities. Due to side magnetic coupling large intercell coupling coefficient is easily obtained for any

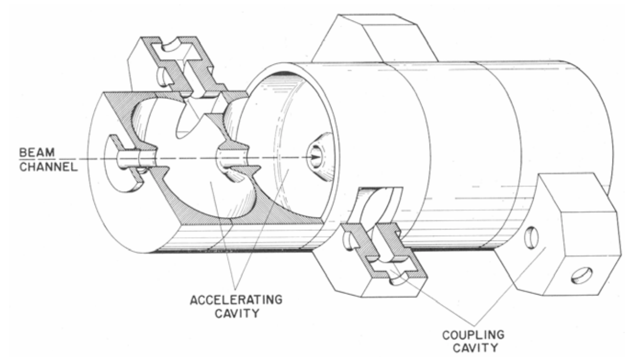


Figure 1: The side-coupled cavity chain [1].

size of beam holes. Low aperture accelerating cells have low field ratios E_{surf}/E_{acc} and H_{surf}/E_{acc}, where E_{surf}, H_{surf} means the maximal electric and magnetic fields into the cell and $\boldsymbol{E_{acc}}$ is the accelerating gradient.

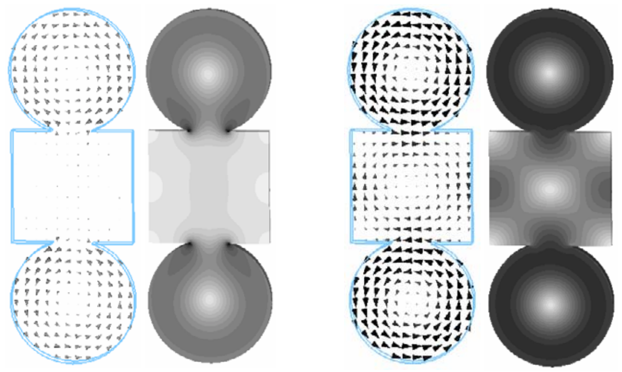
In addition the high coupling allows to use long accelerating cavity because the main limitation factor of cell number for superconducting structure is field nonuniformity [4], which is proportional to $\Delta f/f \cdot N^{3/2} \cdot K_{coup}^{-1}$, where $\Delta f/f$ means average relative error of cells frequency, N is number of cells in the cavity and K_{coup} is the intercell coupling coefficient. Existence of the side resonators allows to carry out main power and HOM couplers into these resonators. Filling factor for such biperiodic structure can achieve 1.

If an accelerating cavity consists of λ/4 instead of λ/2 length cells it gives considerable gain in accelerating gradient due to rising of transit time factor. Transit time factor for single pillbox resonator can be expressed from length of pillbox as:

$$T = \frac{\sin(\theta/2)}{\theta/2} = \frac{\sin(\pi \cdot D/\lambda)}{\pi \cdot D/\lambda}$$

Where θ is transit angle and D is the resonator length. In case of $D=\lambda/2$ $T=2/\pi=0.637$ and for $D=\lambda/4$ $T=2\cdot\sqrt{2}/\pi=0.9$. Since transit time factor means ratio of effective accelerating voltage to maximum cell voltage, accelerating rate of λ/4 pillbox obtains as $\sqrt{2}=1.41$ times higher than in λ/2 length pillbox.

However the well-known biperiodic structure [2, 3] with side coupling cavity is not quite suitable for superconducting accelerator because of prohibitive gain of magnetic field in coupling slot area. It is caused by



a) With high magnetic field in coupling window

b) With low magnetic field in coupling window

Figure 2: Two samples of magnetic coupling between three cavities.

penetration of strong magnetic flux from accelerating cavity to relatively empty side cavity. The penetrating magnetic field considerable gains on corners of coupling slot. Only the same magnitude and direction field in the neighboring coupling resonator can compensate and reduce parasitic transverse magnetic field in the coupling slot (see Fig. 2). In this case operation mode is π and phase shift between accelerating cells is 2π. But allowing for one hundred eighty degrees turn of every next accelerating resonator (see Fig. 3) the total phase shift for them remains π. It defines distance between accelerating cells. The minimum distance is $\lambda/2$ at the $\lambda/4$ cell length.

Figure 3: Electric field distribution for operation mode of the biperiodic structure.

From Fig. 4 it is seen that the resulting accelerating structure can be expanded an identical second one with side coupling cells oriented in transverse plane towards the first structure plane. Thus we obtain standing wave accelerator structure: a combination of two independent substructures, each operating at the π-mode, and each with an independent RF input coupler.

Proper operation of this double-chain biperiodic structure requires that both substructures are tuned to the same resonant frequency, RF power from the RF source must be divided equally between them, and a phase difference of $\pi/2$ between these two RF inputs must be provided. Therefore for beam an accelerating field of this structure will be equivalent to $\pi/2$-mode accelerating structure. But unlike conventional traveling wave accelerating structure [5] the coupling between on-line cavities through the beam aperture can be arbitrary small. It allows to choose cavity geometry with small beam hole.

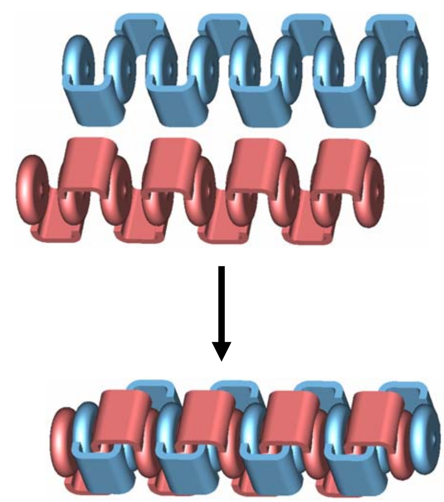


Figure 4: Union of two side-coupled cavity chains into the one SW acceleration structure.

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As an example we will consider 18-cell double-chain biperiodic structure with 20mm aperture and resonant frequency of 1.3GHz. Geometry of two periods of the substructure is shown in Fig. 5. Since the beam aperture is no longer used to couple energy down the system, one has almost complete freedom to change the cavity parameters to optimize efficiency. At first we chose an accelerating cavity shape to minimize the maximal surface magnetic and electric fields for given gradient into the accelerating cell. After that the coupling resonator shaped to obtain proper coupling factor and tuned the cavity chain on retention low magnetic field in area of coupling slot. As coupling resonators there is a short waveguide section, which is made from WR650 with reduced height of 20mm.

The maximal surface electric and magnetic fields in the tuned-up structure achieve approximately the same value into the accelerating and the coupling resonators. If TESLA ratios of the maximal electric and magnetic field strength on the cavity surface to the accelerating rate ($E_{surf}/E_{acc}=2$, $H_{surf}/E_{acc}=4.26 mT/MV/m$) is taken as reference, then this structure has reduction of such ratios by a factor 0.62 both for magnetic and electric fields. The exact values are $E_{surf}/E_{acc}=1.24$ and B_{surf}/E_{acc}=2.63mT/MV/m. By choosing the cavity geometry [5] these ratios can be varied in a wide-ranging.

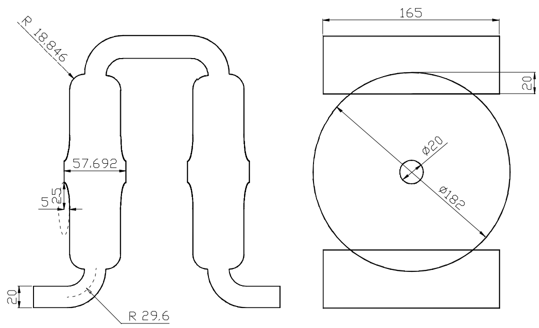

Figure 5: Two periods of the biperiodic substructure.

Dispersion curve of the substructure (see Fig.6) shows the coupling factor obtains 9.72%. It allows to have accelerating field nonuniformity like 9-cell TESLA structure for 27-cell cavity at the same cavity sizes tolerance.

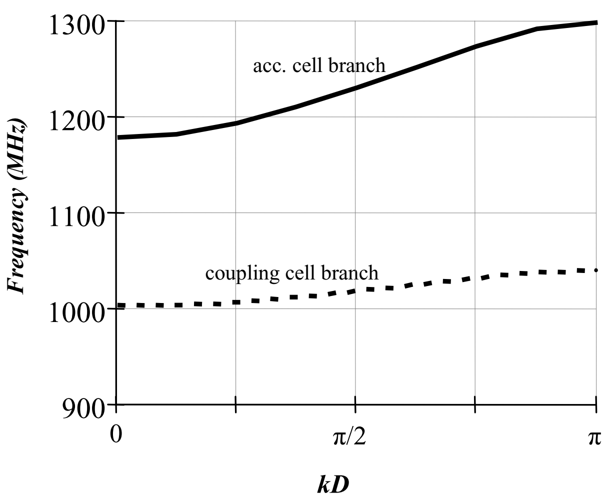

Figure 6: Dispersion curve for double-chain biperiodic structure.

In Table 1 important parameters of the double-chain biperiodic structure and two version of TESLA 9-cell structure are compared.

CONCLUSION

As a result of investigation of new type of standing wave accelerating structure showed that accelerating rate in superconducting accelerator can be significant increased for the achievable surface fields. The most gain of gradient gives small iris radius and large filling factor of the considered structure. Of course, we didn't touch many other appearing problems, which should be solved for this structure. The most evidence of them are:

- Technology of production double-chain biperiodic structure
- Beam dynamics (wake-field)
- Complication of auxiliary system and RF component

Table 1: Comparison between two layout of TESLA 9-cell cavity and double-chain biperiodic structure

Parameter	TTF-1 9-cell cavity	TESLA -500 9-cell cavity	Double-chain biperiodic structure
Active length (m)	1.038	1.038	1.038 - 1.558
Number of cells	9	9	18 - 27
Aperture diameter (mm)	70	70	20
Coupling cell to cell (%)	1.87	1.87	9.72
R/Q per cavity (Ω)	1036	1036	1293
f/ L (kHz/mm)	404	315	61
Filling factor L_{active}/L_{total}	0.747	0.786	≥ 0.94
E_{peac}/E_{acc}	2.0	2.0	1.24
B_{peac}/E_{acc} (mT/Mv/m)	4.26	4.26	2.63
Attainable effective acc.gradient (MV/m)			
at 105mT (TTF-1, 25MV/m in cavity)	18.4	19.4	37.5
at 150mT (present time, 35MV/m in cavity)	26.3	27.7	53.6
at 200mT (theoretical limit for niobium at 2°K)	35	36.9	71.5

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