MULTI-BEAM ACCELERATING STRUCTURES

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Abstract

Motivated by the application to ERL, two-beam structures are designed. The idea is extended to multi-beam structures.

INTRODUCTION

The application of the superconducting cavity to the Energy Recovery Linac (ERL) [1] is an ideal one and possible only with the superconducting cavity. The performance of ERL would be improved by two beam-axis structures. They can lower the energy of the injector, avoid a complex injection beam line and make the optimization of the optics for each beam possible. Thus the beam intensity or the bunch charge could be increased without increasing the beam emittance. Two beam structures are not necessary to be used for a whole Linac. This idea is extended to Multi-Beam Structures. Three beam structures can deliver beams to ERL and SASE-FEL facilities simultaneously, the fourth beam of the four beam structure is for the nuclear physics.

STRUCTURE DESIGN

Multi-Beam Structures are such as structures coupled resonantly by coupling cells or wave-guides, or structures optimized for longitudinal multi-pole modes. In the first type structures, where the coupled resonator model is a good approximation, each structure can keep optimized RF properties of single beam structures, but fabrication, surface treatment and tuning are difficult. Moreover Q and R/Q are low, lower than the second type, due to coupling structures.

The second types are more preferable, if they could satisfy the following requirements quantitatively.

1: Enough beam axis separation for Q-magnets.
2: Good axial symmetry of RF field around beam axes.
3: Reasonable RF parameters of the accelerating/ decelerating mode, R/Q, Hsp/Eacc and Esp/Eacc.
4: Easiness of fabrication and surface treatment.

Notice that the used mode is not the fundamental mode, there are lower frequency parasitic modes. R/Q is low because of a multi-pole mode. So, the optimum operating gradient is not high, about 20MV/m at most.

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Optimization is done by drawing poles away from each other and by squeezing connecting parts. For example, in the case of the two-beam structure, a racetrack cavity is squeezed at the center part in Y (height) and Z (depth) directions, and then we get structures such as shown in Figure 1.

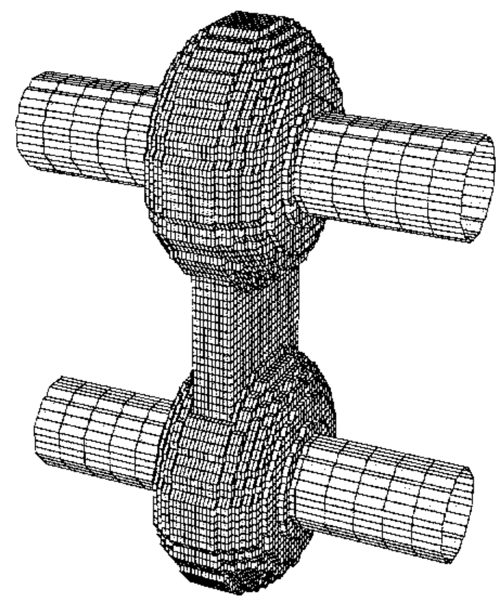

Figure 1: An example of single cell two-beam structures.

Table 1 shows how RF parameters change in this process, where TM-210 is a used mode. From a viewpoint of the RF property, the extremely squeezed case is most preferable. This structure is no longer a single structure but a directly and weakly coupled two-cell structure, thus it has a good axial symmetry around each beam axis. A drawback is that an application of a simple press forming is difficult. Probably half-cells have to be formed in two pieces and welded. A common problem of other examples in Table1 is that the lower frequency parasitic modes, TM-110 or asymmetric magnetic field modes have a finite transverse magnetic field at beam axes. They and other higher order modes, TM-310, TM-410 and so on, are longitudinal modes and deflecting modes at the same time. A quantitative discussion of the effect of these modes is given in the next section.

The same process can be used to design multi-beam structures, 3, 4 lateral chains, four-leaf clover and so on.

Table 1: Parameters of single cell two-beam structures

Type	Mode	Frequency	R / Q	Esp / Eacc	Hsp /Eacc	Geometrical Factor
		MHz	Ω		Oe / MV / m	Ω
Race Track	TM-110	750	33	3.4	100	180
	TM-210	940	57	2.1	56	250
Strong Couple	TM-110	705	18	7.2	207	106
Y=25, Z=4cm	TM-210	996	55	1.9	49	210
Medium Couple	TM-110	906	39	4.0	130	150
Y=16, Z=4cm	TM-210	990	59	1.9	43	230
Weak Couple	TM-110	994	54	1.9	57	226
Y=10, Z=4cm	TM-210	1000	63	1.9	40	237

COMPROMISED TWO-BEAM STRUCTURE

As is mentioned above, a troublesome problem is an appearance of longitudinal/deflecting modes. This is because pole axes are different in each mode. Therefore, these modes have a longitudinal E-field and a transverse H-field on beam axes, so they are excited by beams and deflect beams. Although the effect of these modes on beams has to be investigated quantitatively, the induced transverse magnetic field is not so much if the resonance build-up of the modes does not happen. The built-up voltage at the stationary state is given by

$$V = \{k\cdot q/\sin(\delta/2)\}\exp\{j(-\pi/2\pm\delta/2)\}, \quad |\delta|>>\tau . \qquad (1)$$

Where k: loss parameter, q: bunch charge, δ: phase slip of the modes per bunch interval, ±: phases at just before (+) and after (-) bunch passing and τ: bunch interval divided by filling time. If δ is small, V becomes large but the E-field delayed or advanced by π/2 and bunches do not feel E-field. However H-field is π/2 advanced from E-field, bunches feel the maximum deflecting field. In Table 2, some RF parameters of several optimized single cell two-beam structures at 1GHz are summarized. They are designed with beam axes separation (X) of 32, 34cm and some different height (Y) and depth (Z) of the coupling part. The integral of the transverse magnetic field ($\int$ Ht) is done along the beam axis with transit time factor. The last column is the transverse magnetic field integral, which is induced by the beam of 1nC and 1nsec interval. They depend on the frequency and the bunch interval through δ of Equation (1). The numbers in this column have to be doubled in ERL mode and are several times larger in multi-cell structures. It can be seen that TM-110 and TM-310 are dominant modes. Unfortunately, calculation shows that these two modes deflect the beam to the same direction. Anyway, taking all things together, the deflecting force is about 10mGauss·m for 1A ERL operation, and then the 10MeV beam is deflected by about 30μrad by a 1m structure. Since this is rather stationary force, the effect could be corrected it necessary. It should be noticed that in the transient state the induced field is swinging and sometimes becomes twice as much as the stationary state.

The deflection is reduced by one order with a multi-cell structure coupled by one-cell like shown in Figure 2. The detailed design is still under way.

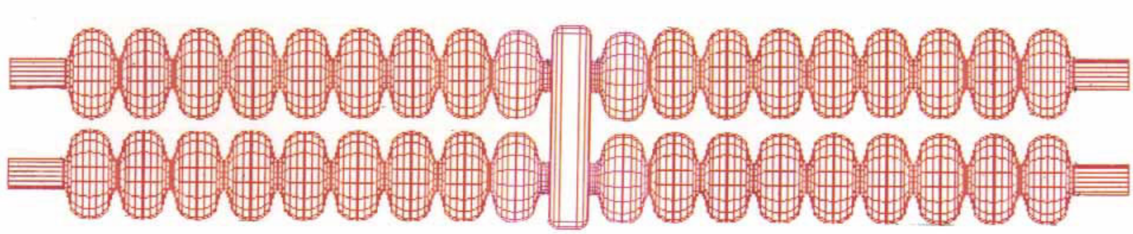

Figure 2: An example of single cell coupled multi-cell two-beam structures.

Table 2: Parameters of single cell two-beam structures

Type	Mode	Frequency	R / Q	Esp/Eacc	Hsp/Eacc	(∫ Ht) / Vacc	(∫ Ht) / q
X / Y / Z	TM-XYZ						
cm		MHz	Ω		Oe / MV / m	Oe ·m / MV	mGauss·m / nC
Type A	TM-110	851	19			13	0.64
34 / 18 / 4	TM-210	998	53	2.0	62	3.8	
	TM-310	1088	39			2.0	0.47
	TM-410	1328	2.6			17	0.06
	TM-510	1502	0.01			71	~0
Type B	TM-110	922	34			7.5	1.5
34 / 16 / 4	TM-210	996	57	1.9	57	3.0	
	TM-310	1104	26			4.3	0.56
	TM-410	1358	1.1			28	0.03
Type C	TM-110	973	52			3.9	3.6
34 / 14 / 4	TM-210	997	58	1.9	52	2.5	
	TM-310	1187	7.1			11	0.21
	TM-410	1387	0.4			41	0.01
Type D	TM-110	972	52			4.8	4.3
32 / 14 / 4	TM-210	1000	58	2.0	45	3.3	
	TM-310	1204	7.5			9.7	0.18
	TM-410	1410	0.6			31	0.01
Type E	TM-110	968	51			4.1	3.2
34 / 14 / 5	TM-210	994	59	1.9	52	2.7	
	TM-310	1190	7.7			11	0.23
	TM-410	1376	0.6			36	0.02

SUMMARY

Multi-beam structures are proposed and some two-beam structures are designed. If two-beam structures are used for lower energy part of ERL, they could improve the beam quality very much. Multi-beam structures are also promising. For example, an accelerator complex of an 1GeV 3-beam Linac and a 4GeV single-beam Linac can deliver 5GeV beam to ERL facility and 5GeV beam by 5-pass recirculation to a SASE-FEL or a nuclear physics facility.

REFERENCES

[1] Lia Merminga, "Recent Developments in Superconducting RF Free Electron Lasers", Proc. of 10th Workshop on RF Superconductivity, Tsukuba, Japan (2001) p202-211.