ADDITIONAL DESIGN CRITERIA FOR LOW β STRUCTURES

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Low β structures are used in proton and ion accelerators. This paper is restricted to additional design criteria for the superconducting accelerator projects. The room-temperature booster at Heidelberg, [1] and the design of room-temperature proton and heavy ion linacs will not be included. Essential elements stimulating the increasing activity are the development of new accelerating structures uniquely suited to the acceleration of very low velocity heavy ions. The helix resonator [2-5], the split-ring resonator [6,7] and the reentrant cavity [8] have been developed as superconducting accelerator structures for low-velocity applications. Fig. 1 shows the Karlsruhe helix resonator, fig. 2 shows the Argonnne split ring-resonator and fig. 3 the Cal Tech /Stony Brook split loop. All of the new structures consist of a large number of independently phased resonators which may be adjusted to accelerate ions over a wide velocity range without changing the frequency. The velocity profile is established by phasing rather than by increasing lengths of successive accelerating units. Since the velocity need not to be matched to the resonator length, the projectile phase may change greatly while it traverses the structure. Nevertheless, phase focussing is present in the same way as in a multiple cell structure with a well-established velocity profile. Such a linac is exceedingly flexible with regard to the mode of operation and hence is tolerant of sub-standard performance of resonators. A failure of resonators to provide the design accelerating field will reduce the maximum beam energy, but the linac still can be used efficiently. On the other hand, if needed energy variability is easily achieved by varying the phase of individual resonators.

Thus, for a given particle velocity range an average β-value is chosen and identical resonators for a fixed frequency can be designed. The frequency, in turn is a compromise between the desire to have as low a frequency as possible (to minimize the bunching problem and to maximize the accelerating length of an individual unit) and the desire to limit the radial dimensions and the stored energy. Higher frequency means lower stored energy which simplifies phase and amplitude control. But more essential is the mechanical rigidity of the resonator. Vibration induced frequency modulations have to be compensated by rf control. 9) If the structure is mechanically stiff, the rf frequency is insensitive to mechanical vibrations and in turn makes feasible phase and amplitude stabilization by direct rf feedback. If the vibration-induced frequency modulations exceed a certain limit a fast tuning unit must be used. Fast tuners based on a voltage-controlled reactance, PIN diodes, have been developed, which can switch up to 10 kilowatts of rf reactive power [9,10]. But of course the problem of the fast tuning unit is magnified with low mechanical rigidity and with increased stored energy. As a measure for the rigidity the vibration-induced frequency modulation Δf (Hz peak to peak) is used and the radiation pressure frequency shift Δf_{Stat} at a given field level.

Another key design decision for a superconducting low β structure is wether to mount the fast tuning element directly to the resonator or use a high-power rf coupling line for the fast tuner. Both possibilities have been realized successfully, but have different disadvantages. The pin diodes are inaccessible in case of failure [6] (Argonne), the high-power rf coupling lines show multipactoring and gas discharge problems at the cold rf window [3] (Karlsruhe).

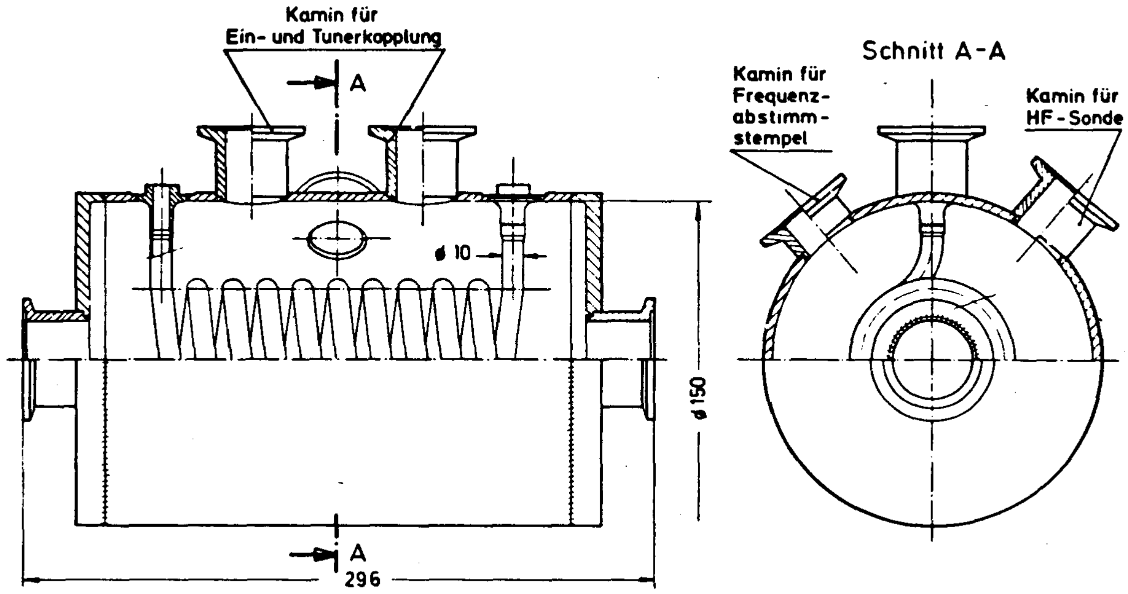

Fig. 1: Single $\lambda/2$-helix-resonator, operating frequency 108 MHz

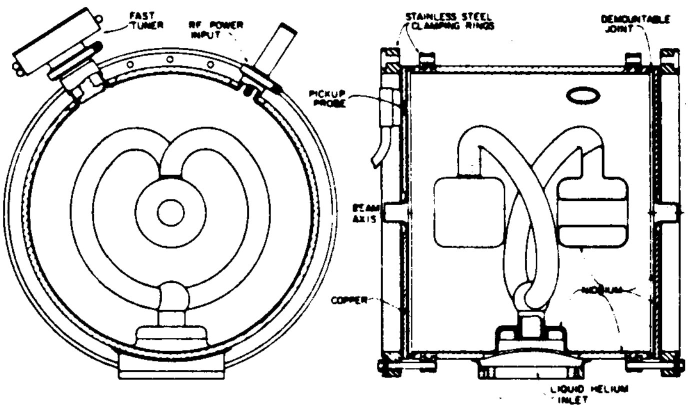

Fig. 2: 97-MHz, 14-in. length, high-beta split-ring resonator. The inner loading structure is made of Nb and is hollow to permit cooling by forced-flow of liquid helium. The outer housing is formed of an explosively-bonded Nb-Cu composite and is cooled by conduction.

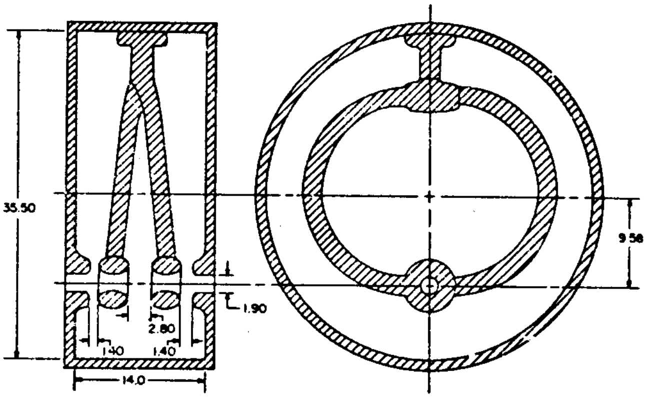

Fig. 3: The β = 0.055 150 MHz prototype split loop cavity of Cal Tech/Stony Brook. Dimensions are in cm.

In addition, low surface fields and good cooling are required for the new structures. In comparison to β = 1 structures the ratio of peak to average surface field is exceedingly higher for low β-structures. The split-ring resonator has been designed for E_p/E_{acc} = 6.3, whereas the $\lambda/2$-helix resonator with E_p/E_{acc} = 12.0 is less favorable from this point of view. Recently a new type of helix resonator has been developed at Karlsruhe [5], the tapered helix resonator, to reduce E_p/E_{acc}.

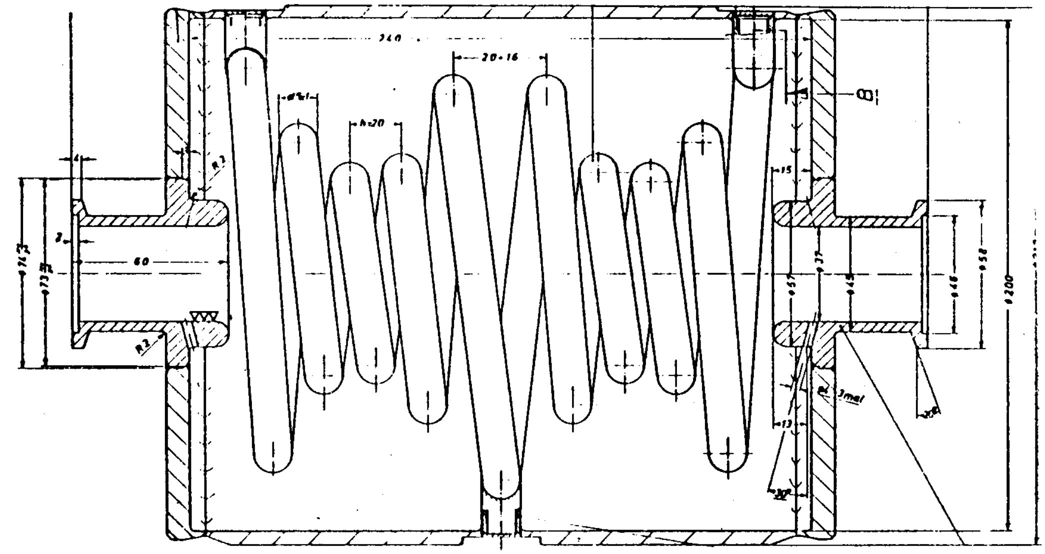

Fig. 4: Design of the Niobium test cavity with a ratio of the electric fields $E_{peak}/E_{trav.wave\ eff} = 7.1$ and an optimum relative particle velocity $\beta = 0.092$ (Karlsruhe).

The ratio of peak to average field is $E_p/E_{acc} = 7.1$ and the vibration-induced frequency modulation is 350 Hz (peak to peak), thus this helix resonator is comparable with the split-ring resonator. The significant parameters of the helix resonator and the split-ring resonator are summarized in table 1.

Table 1: Parameter of low β-structures

	β	f_o MHz	Δf_{stat} kHz	Δf_{pp} Hz	E_{acc} MV/m	E_p/E_{acc}
λ- helix (Karlsruhe)	0.09	108	90	500	3.0	12.0
tapered helix (Karlsruhe)	0.092	1o'	48	350	2.2	7.1
splitring (Argonne)	0.06	97	10	300	4.0	7
splitring (Cal Tech)	0.055	150	75	360	3.0	6.3
re-entrant (Stanford)	0.1	430	120		12.0	
Alvarez (Karlsruhe)	0.1	720	-	<10	3.0	7.1
Slotted iris (Karlsruhe)	0.2	720	-	-	5.0	3.1

The maximum obtainable accelerating fields for the split-ring resonator seem to be limited by cooling of the central drift tubes. The Argonne split ring has large drift tubes formed of pure niobium which are hollow and cooled by forced flow of helium. Difficulties have been encountered with obtaining proper flow of liquid helium within the resonators. Each arm of the split-ring assembly has a high point which will accumulate helium gas generated by the rf power loss in the resonator. Some resonators seem proberly cooled and will operate at gradients greater than 3.5 MV/m, while the average obtainable cw field is limited to 3 MV/m.

The Cal. Tech/Stony Brook split-ring resonator is fabricated from OFH copper pieces joined by electron beam welds and plated with a ∿ 15 micron thick layer of lead. The cooling properties are somewhat better by conduction cooling of the solid copper drift tubes. The accelerating gradients are limited due to field emission and the relatively low Q-value of the lead plated resonator.

In comparison the obtainable gradients with the Karlsruhe helix resonators are limited due to field emission only . The cooling by forced flow of helium is superior compared to the split-ring.

Also included in table 1 is the re-entrant cavity, which has been developed at Stanford on the technology for the Stanford superconducting electron linac [11]. The good features of the design are axial symmetry which eliminates beam steering effects, wide velocity acceptance of a single gap structure and good mechanical rigidity. These advantages are obtained at the cost of an exceptionally strong sensitivity to multipacting, a low average field gradient and an uncomfortably high rf frequency (430 MHz)

Completely different low β structures for the acceleration of protons are the 5 cell Alvarez-resonator [12] (fig. 5) and the 2 cell slotted Iris resonator which

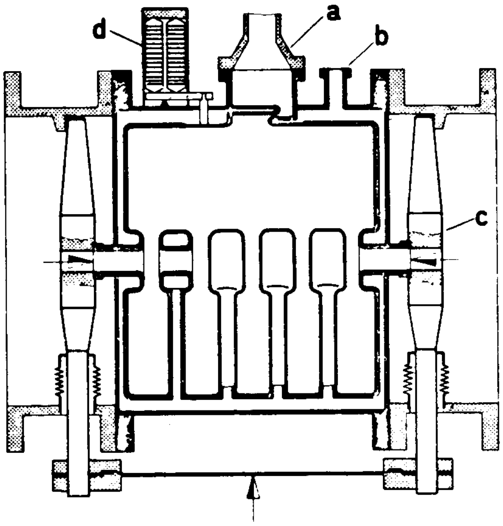

Fig. 5: 720 MHz Alvarez for 5.8 MeV protons to be used in prototype accelerator, showing also rf input (a), helium input (b), mechanical tuner (c), piezotuner (d)

have been developed at Karlsruhe for a frequency of 720 MHz. The structure diameter is about 30 cm, the geometry was optimized with the help of the LALA-program. The slotted Iris has four circular slots per disc with 4.6 cm diamter, giving a passband of 17 MHz.

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