HALF WAVE HELIX LOADED SUPERCONDUCTING RESONATOR FOR THE SACLAY HEAVY ION LINAC

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We report here the main characteristics and performances of the helix superconducting resonators designed and mounted in the new Saclay Booster Linac which is the first european heavy ion superconducting accelerator.

Introduction

We have realized helix loaded superconducting resonators, made of solid niobium and operated at 4.2 K. 50 resonators are mounted in the 8 cryostats of the Saclay-Tandem-Booster. This accelerator has already been operated for physics experiments, and provides heavy ions beams from ^{12}C up to ^{74}Ge with energies of 12 MeV/A for the lightest one and 6 MeV/A for the heaviest. The main features of the resonator is the internal half wave helix used as a velocity matcher. We have two different kinds of helices: 16 half-wave resonators ("two gap" structures) better suited for low beam velocity, and 34 full-wave resonators ("three gap" structures). We started the construction of the series of resonators with "three gap" structures based on a first study elaborated at Karlsruhe [1], and designed later the "two gap" structures.

In this paper we shall give the main features of these resonators, especially the quality factor and the energy gain per charge measured with a ^{12}C beam. The important advantages of these new structures are the broadness of the transit time factor curve which allows us to accelerate low velocity beams with good efficiency, and the simplicity of the mechanical design which only requires two helix welds.

Helix design and field distribution

Main characteristics of the resonator are given below.

Table 1

Mechanical and electrical characteristics of half wave resonator

Mechanical characteristics		
Length of the cavity (+ beam tubes)		330 mm
Length of the "gap" (g)		80 mm
Distance between the two gaps (d)		120 mm
Can diameter		225 mm
Beam tube diameter		40 mm
Helix tube diameter		15 mm
Total length of the helix		303 mm
Electrical characteristics		
Eigen frequency	(F)	81 MHz
Average accelerating field	(Ea)	2,15 MV/m
Maximum electric field	(Ep)	16 MV/m
Maximum magnetic field	(Bp)	700 G
Q value	(Q_0)	2×10^8
Geometrical factor	(G)	9 Ω
Energy gain per charge	($\Delta W/q$)	535 keV
Optimum velocity	(V_{opt})	0,085 c

The potential along the helix has a sinusoidal shape. In order to lower the peak electric field to an acceptable value (16 MV/m is the maximum field which can safely be obtained in our full-wave structures), we had :

- to increase the pitch between the two first and two last turns so as to reduce the longitudinal electric field ;
- to increase the distance between the can and the middle turns, where the potential is maximum, so as to reduce the radial electric field.

These constraints lead to a complex helix geometry (Fig. 1). In particular, such a structure has no cylindrical symmetry and a 3D computer model for an accurate calculation of the field distribution was lacking. Measurements of magnetic and electric fields have been done by perturbation methods [2] using metallic and dielectric spheres (ø : 3 mm).

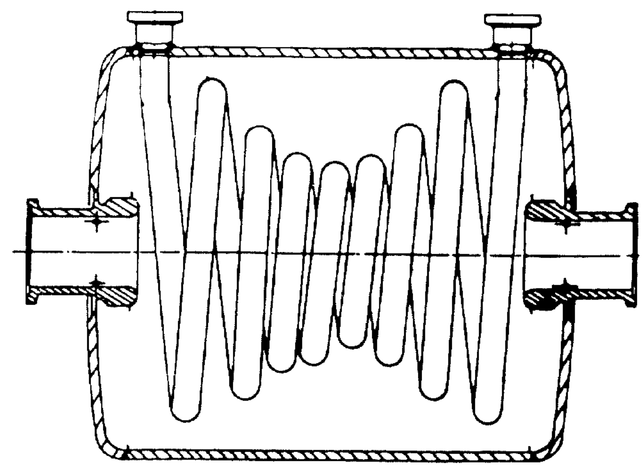

Fig. 1 - Half wave resonator. Helix Design.

The geometry of the helix has been optimized [3] to get the highest value of the ratio : accelerating field over peak electric field (0.135).

The maximum magnetic field (700 G) is located at the elbow in the welding region.

The electric field on the beam axis is a continuous distribution (Fig. 2), the "two-gap" structure being actually an approximation. The transit time factor curve for both structures (Fig. 3) shows that for

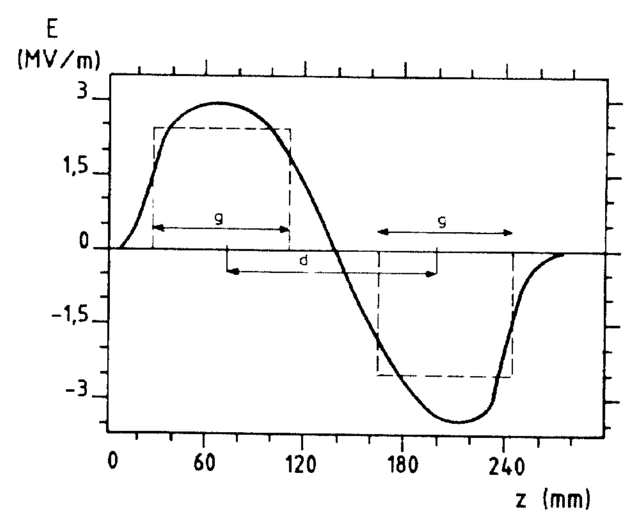

Fig. 2 - Accelerating field along the beam axis.

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low velocity (β = 0.05) and high velocity (β > 0.12) the half-wave resonator has a better efficiency. 16 such resonators have been mounted in the first and last large cryostat of the machine.

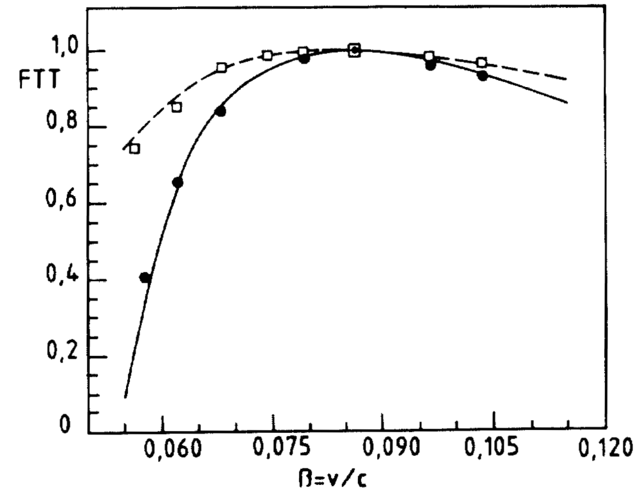

Fig. 3 - Normalized theoretical transit time factor for half-wave (--) and full-wave (-) resonators and experimental points.

Liquid helium tests

Each resonator undergoes a chemical polishing (1-1-2 buffered mixture) to remove about 80 µm. The cavity is then rinsed with filtered high purity water (17 MΩ.m) in dust free laminar air flow (class 100). After chemistry and rinsing operations, the resonator is mounted under laminar air flow in our test cryostat and checked.

We measure Q value versus accelerating field and we localize by the second sound method, described, below, the hot point which induces the quench.

Q value measurement

The Q value is an essential parameter of superconducting resonators. It governs the power consumption at 4.2 K and thus conditions the cooling system design.

The low field Q value for both kinds of resonator is around 3×10^8. Fig. 4 shows the tremendous importance of mounting the cavity under laminar air flow to prevent it from dust contamination.

During the first test, done without this precaution, we observe field emission (Q value decreases sharply as soon as the accelerating field gets beyond 1.0 MV).

During the second test, done with laminar air flow mounting, we get :

- a better Q value due to a light chemistry of the resonator ;
- no more field emission : the Q value is still of the order of 3×10^8 even at a high accelerating field (2.1 MV).

Defect location

Decreasing the temperature of the helium bath down to 1.6 K, we use an important property of superfluid helium : heat pulses induced by the quench can propagate inside the helix (the second sound velocity is 20 $m.s^{-1}$ at 1.8 K). The quench position is determined by the time difference between pulses observed with two fast heat detectors (Allen-Bradley carbon resistances). The defect position can be localized with a precision better than 0.5 cm. Most of the time this position is located at welds in which have sometimes been observed metallic inclusions from the TIG welding electrode.

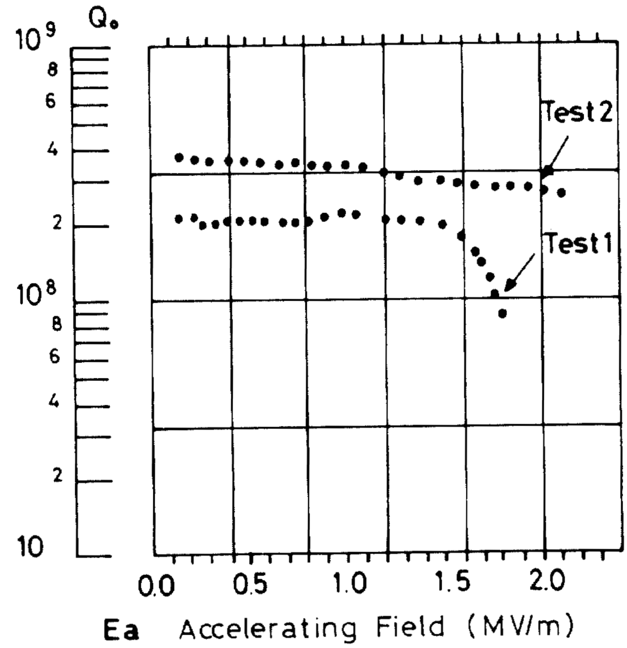

Fig. 4 - Q value versus accelerating field.

Magnetic field shielding

Because of the natural earth field, magnetic field vortices are created in the superconducting niobium during cooling.

In these vortices, the magnetic field remains close to Bc and niobium is normal conductor [4]. The consequence is an increase of RF losses. The Fig. 5 shows the influence of shielding on Q values. Especially, with shielding the power necessary at 4 K to operate this particular cavity at an accelerating field of 2 MV/m is 4 W, but without shielding, the same power is needed already at 1.4 MV/m. These measurements are done in our test cryostat. The actual average power consumption per cavity at 2 MV/m is about 2 W.

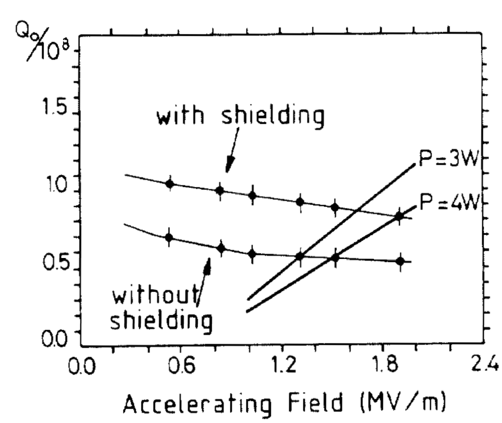

Fig. 5 - Influence of shielding on Q value and 4 K power consumption in the test cryostat.

Vibrations

For such devices, vibrations are a crucial problem. Vibrations induce large frequency displacements well outside the narrow bandwith of superconducting cavities. It is impossible to lock the phase of the accelerating field on the master oscillator of the machine without strong coupling and as a consequence : very important reactive power exchange is taking place between the cavity and the outside.

To overcome this difficulty [5] each cavity of the machine is connected to an external voltage controlled reactance (VCX) dynamically adjusted to compensate the variations of the cavity eigenfrequency. The RF power requested from the RF amplifier is 130 W.

Conclusion

On beam test

Half-wave resonators have been tested with a continuous ^{12}C beam delivered by the FN tandem.

The behaviour is very similar to the theoretical calculations done with the field distribution measurements (cf. Fig. 3). The accelerating field achieved is 2.15 MV/m corresponding to an energy gain of 535 keV per charge.

The complete Booster which has now 16 half wave resonators in the first and last large cryostats, allows us to extend the range of mass from A=12 up to at least A=80 with excellent optical and dynamical beam qualities.

Références

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