A NEW TYPE OF ACCELERATION CAVITY FOR THE HEIDELBERG TEST STORAGE RING TSR

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Summary

For experiments with cooled, highly stripped, heavy ions at the Max-Planck-Institut für Kernphysik, a rf cavity for deceleration down to verlocities corresponding to a magnetic rigidity of B·q = 0.2 Tm was developed.
This synchrotron cavity utilizes a novel scheme for magnetization using a magnetic quadrupole field. The power tests of the cavity showed a stable operation of the fast frequency control and a range of frequency variation by magnetization of a factor 9 even higher than expected. The total frequency range of the cavity is 0.45 MHz to 12 MHz, at 10 kW power input the obtainable gap voltage is 5 kV_p.

1. Introduction

The Heidelberg Heavy Ion Test Storage Ring TSR [1] is a 55,4 m circumference low energy cooler ring with four fold symmetry, see figure 1. The injection line from the MP-Tandem Postaccelerator Combination [2] can be seen in the middle right of the figure guiding the beam to the electrostatic septum. The electron cooler is situated in the next straight section, the experimental area in the third section, and the rf-resonator in the last one.

The maximum magnetic rigidity of the beams delivered by the Heidelberg Tandem-Postaccelerator is typically 1.1 Tm ($^{12}C^{6+}$ 15 MeV/u, $^{127}I^{47+}$ 8 MeV/u). The magnetic rigidity of the storage ring can cover the range between 0.2 - 1.5 Tm. In order to obtain heavy ions corresponding to this range of magnetic rigidities, at MPI a new type of ferrite loaded resonator was developed, able to stack accelerate or decelerate heavy ion beams covering a frequency range between 0.45 and 12 MHz with a fast tuning capability of about 9:1. After the description of the resonator itself the measured electrical parameters are presented.

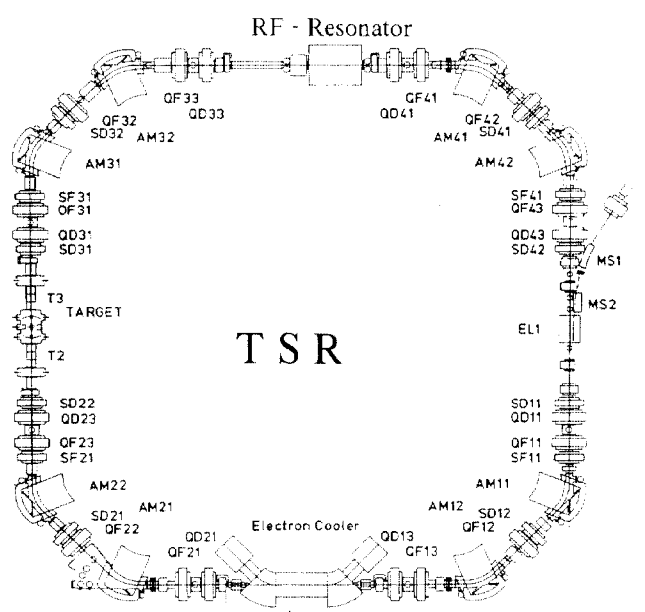

Fig.1: Layout of the Heidelberg Heavy Ion Storage Ring TSR with its main components. The labels designate: AMX - dipol magnets, QDX (QFX) quadrupole magnets, SDX (SFX) sextupole lenses, MSX magnetic septa, EL1 electrostatic septum. The rf-resonator is located in the upper straight section.

2. Ferrite Loaded Resonators

For acceleration and deceleration of nonrelativistic heavy ions on closed orbits variable frequency ferrite loaded resonators are widely used [3,4], in one case with magnetization by a dc-dipole field [5].

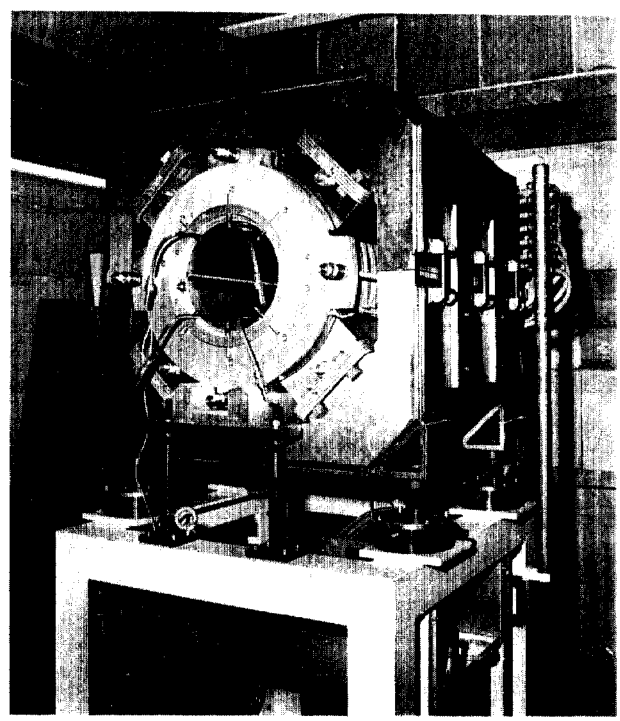

Fig.2: The Quadrupole Ferrite Loaded Resonator QFLR

The principal advantages of such resonators are the possibility of the fast wide range frequency regulation and the compact construction.

The resonance frequency variation is realised by changing the ferrite permeability with a d.c. magnetisation field. Most of the existing resonators have a simple coaxial quarterwave geometry. The magnetisation field is produced by several bias windings mounted directly on the ferrite rings and connected to a regulated power supply able to deliver several hundreds till 1000 A. The variation of the d.c. bias changes the incremental permeability μ_Δ and this way the resonance frequency is changed. The inside construction of these resonators is complicated by the necessary ferrite rings' support and the bias windings which reduce the ferrite volume. Also, the rf-voltage induced in the bias windings necessitates supplementary rf-filters which may lead to some parasitic resonances [6,7]. In order to avoid this resonances a careful and lengthy tuning process is necessary.

3. The Quadrupole Ferrite Loaded Resonator

At the Max-Planck-Institut für Kernphysik, Heidelberg, a new type of ferrite loaded resonator was developed: the quadrupole ferrite loaded resonator (QFLR) [8]. Figure 2 shows the overall view of the QFLR assembled for the test measurements. Figures 3 and 4 show the cross section and the cut away drawing of the QFLR giving the principal details of this type

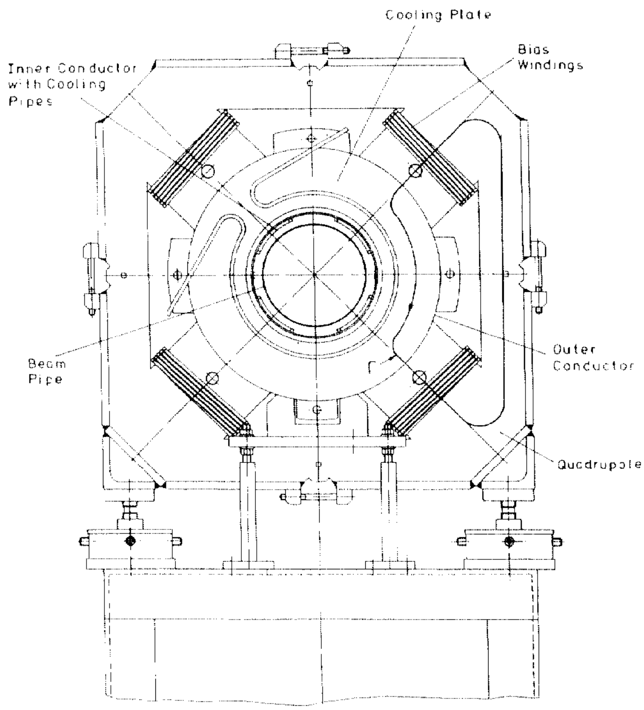

Fig.3: Cross section of the quadrupole ferrite loaded resonator

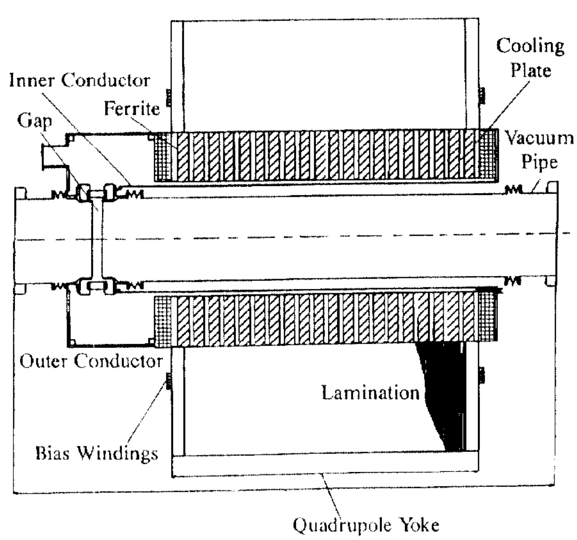

Fig.4: Cut away drawing of the quadrupole ferrite loaded resonator

of resonator. The space between the inner and the outer conductor of the λ/4 line resonator is filled with ferrite rings and copper cooling plates. From electric strength considerations a clearance (radial dimension - 10 mm) is needed between the inner conductor and the copper cooling plates . The magnetic bias field is created by an external quadrupole with 5 bias windings on each magnetic pole. In order to reduce the necessary d.c. power the space between the ferrite rings and the quadrupole poles must be as small as possible.

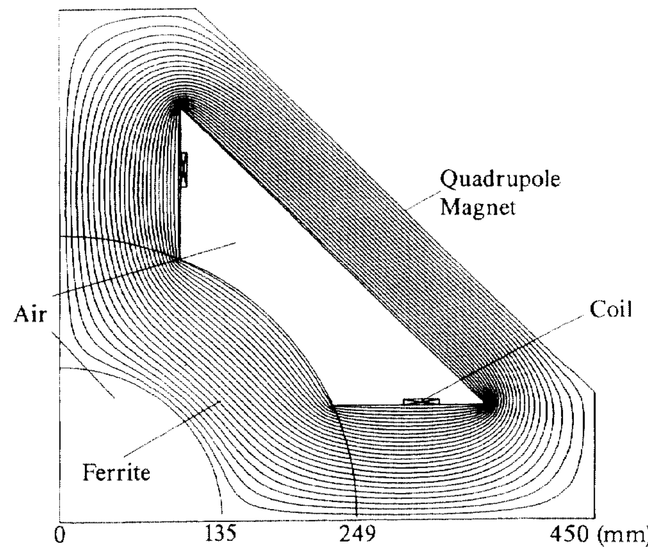

Fig.5: Calculated field lines in the quadrupole ferrite loaded resonator with the Poisson program

The general layout of the excitation magnet was done with the help of the POISSON program [9]. Figure 5 shows a field line plot for one quarter of the quadrupole.

The necessary gap voltage of the resonator depends on the operation mode it is used for

Particle	Energy [MeV]	Harmonic Number	Momentum Spread $\Delta p/p$	U_{HF}(a) [kV]
$^{12}C^{6+}$	174	1	±0.0052	5.04
		4	±0.0026	5.04
$^{16}O^{7+}$	96	2	±0.0052	4.98
$^{58}Ni^{21+}$	452	1	±0.0058	4.93
		9	±0.0020	4.95
$^{127}J^{31+}$	840	2	±0.0052	4.95
$^{197}Au^{32-}$	1003	2	±0.0034	4.98
		14	±0.0013	4.96

Particle	Energy [MeV]	$U_{HF}(b)$ [V]
$^{12}C^{6-}$	174	130
$^{16}O^{7+}$	96	80
$^{58}Ni^{21+}$	452	90
$^{127}J^{31+}$	840	80
$^{197}Au^{32+}$	1003	70

(Table 1) Necessary gap voltage for adiabatic capture(a) and acceleration(b) of different ions in TSR: the acceleration or deceleration of stored particles in typically 4 s and, as an extreme case, the adiabatic capture of a whole particle stack stored by the rf-stacking method.

The voltage necessary for acceleration or deceleration of a pure multiturn stack is with typically 100 - 200 volts relatively small and causes no specific problems.

For the adiabatic capture of rf-stacked particles with momentum spreads in the order of 1% voltages as high as 5 kV_p are needed.

To illustrate the quite different requirements voltages for representative ions are given in Table 1.

4. Radio-frequency Measurements at the QFLR

The new type of resonator was tested under low and high power conditions. First of all, the dependence of μ_Δ on the magnetic excitation field was examined as can be seen from figure 6. Here μ_Δ is plotted versus the excitation current in the quadrupole windings. The resulting variation of the resonance frequency

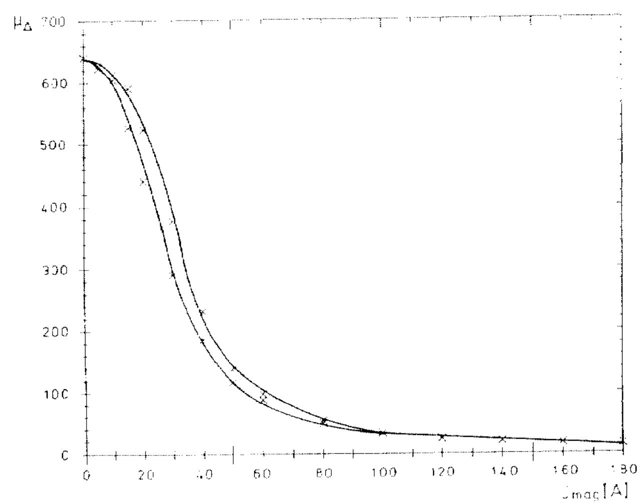

Fig.6: The ferrite incremental permeability μ_Δ versus the QFLR bias current for increasing (upper curve) and decreasing bias current

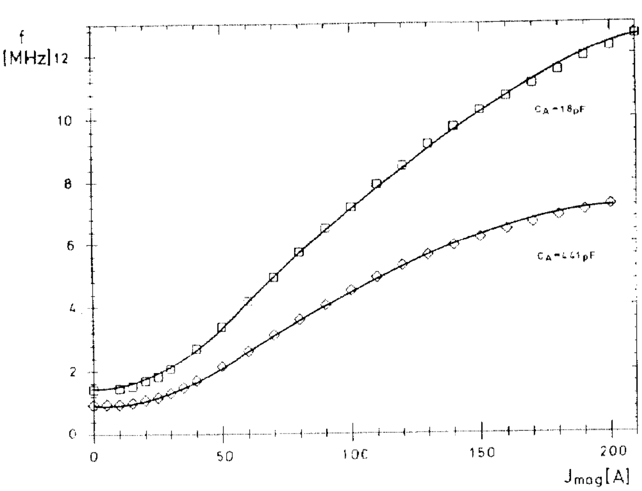

Fig.7: Resonance frequency versus bias current for two different loading capacities

	Design	Measurement
Frequency Range	0.5 - 9 MHz	0.45 - 10 (13) MHz
Fast Frequency Shift	Factor 5.5	Factor 6.5 (9)
Peak RF Voltage	5 kV	5.2 kV
RF Power	10 kW	11 kW
RF Power Density	150 mW/cm^{-3}	•
Ferrite Material	Philips FXC 8C12	•
Dimensions	498x270x25 mm^3	•
Number of Ferrite Rings	20	•
Cooling	21 water cooled copper disks	•
Bias Current	150 A	150 A (200 A)
Ramp Time (frequency change factor 5.4)	4 sec	3* sec
Vacuum	$< 10^{-11}$ mbar	•

(Table 2) Design and measured values of the QFLR

* limited by the power supply used

is displayed in figure 7 for two different loading capacities. For a value of this capacity of only 18 pF the extremely large frequency variation of 9:1 is achieved.

High power tests have been performed with a 10 kW amplifier. At the maximum value fully coupled to the resonator a peak voltage of 5kV could be achieved without any problems. A comparison between the design parameters and the measured values is given in table 2.

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