DEVELOPMENT OF A PULSED LIGHT-ION ACCELERATOR MODULE BASED ON HALF-WAVE RESONATORS

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Abstract

A new injector for the cooler Synchrotron COSY at FZ Juelich has been projected based on half-wave resonators. The first prototype of the inductive RF power coupler has recently been built and will be used to operate the prototype cavities in a vertical bathcryostat. The coupling is adjustable to get a loaded Q of 10^6 to 10^9. Concerning the cavity, different mechanical tuning concepts have been analysed. One solution is now under fabrication including a piezo fine tuner to compensate the Lorentz-force detuning. The design of cryomodul, which houses four cavities, takes into account the restricted space of the linac.

HALF-WAVE RESONATORS

The main design had been changed from quarter-wave (QWRs) resonators to halve-wave resonators (HWRs) due to the intolerable emittance growth and vertical beam kick of the QWRs [1]. The decision to use HWRs required the development of new tuning and preparation procedures of the cavities. The basic parameters of the cavities are summarized in the following table.

Table 1: Main parameters of HWRs. The hypothetical accelerating length to calculate E_{avg} has been defined to $l = ß\lambda$.

	160MHz	320MHz
β	0.11	0.2
R/Q in Ohm	249	244
B_{peak}/E_{avg} in mT/MV/m	10.4	9.4
E_{peak}/E_{avg}	4.5	4

CRYOSTAT DESIGN

The major concern at the development of an optimized cryostat was to meet the main parameters fixed by the beam dynamics and by the requirements of cavity operation. Simply modifying existing designs [2] was not possible even so some ideas could be transferred.

In order to reach the high accelerating gradient, a clean vacuum system is necessary. This was thought to imply the separation into beam and insulating vacuum, having many consequences on the cryostat layout.

On the other hand, beam dynamics calculations have shown that the length of the unit cell must not exceed 1.7 m. Taking into account the length of the room-temperature diagnostic section and the focusing quadrupol doublet between the cryomodules the cryostat itself may have a maximal length of 1.2m in beam direction. This restricted space together with the need for separated vacuum systems was a major concern, leading to an unconventional design. The outer vacuum vessel has a round shape, while the diameter changes in the region of the beam tube, leading to an angled surface (see fig. 1)in this part.

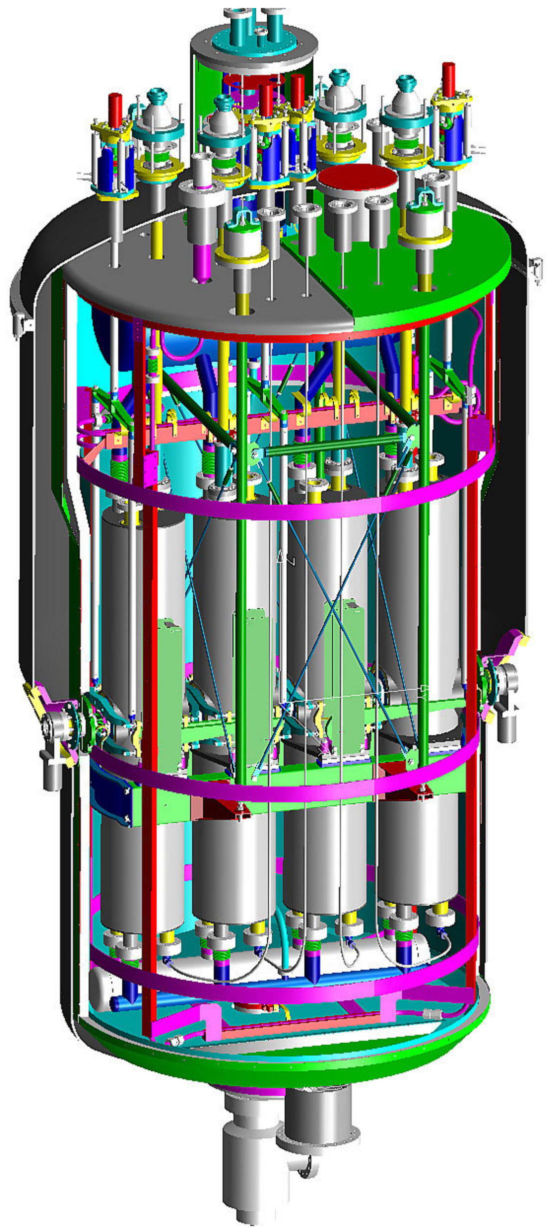

Figure 1: The cryomodule housing 4 resonators.

A top loading design approach was chosen to allow for easy mounting. The cavities including the tuner will be mounted to their support inside a clean room. The coupling port will be closed by a siphon-shaped ceramic part. Closing the valves mounted to the beam tubes this assembly will be immersed into the cryostat vessel outside the clean room, where angled plates in the beam tube seals against the cryostat vessel. Finally the valves will stay outside the cryostat at room temperature, an idea adopted from [3].

As a side effect, the separate beam vacuum allows the use of standard cryogenic techniques such as multilayer insulation (MLI) to reduce the heat transfer due to radiation, MLI must not be used in a common vacuum system.

The spacing between the resonators was kept at an minimum value of 56 mm, the length of the cold-warm transition at the beam tube amounts to only 70 mm, leading to an high real-estate gradient of about 2.7 MV/m within a unit cell. To ensure that the heat transfer via the beam ports is affordable numerical calculations have been performed, the results can be viewed in fig. 2. The total heat transfer to the cavity (due to radiation and heat conductance over the bellows) via the beam ports was found to be less than 0.1 W.

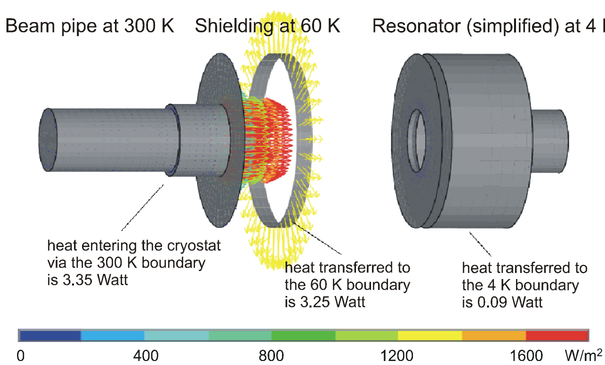

Figure 2: Numerical calculation of the heat transfer for the cold–warm transition at the beam tubes, assuming an intermediate cooling temperature of 60 K.

An additional pumping port connected to the bottom of the cryostat can be used to lower the vacuum pressure inside the innermost cavities, if this is necessary.

The cavity cooling is provided by liquid helium at 4.2 K. Therefore, a reservoir with approx. 34 l volume is located above the resonators (housed inside individual helium vessels), feeding them via an open cycle thermosiphon. To keep the system as simple as possible, the cooling of the radiation shield and the thermal intercepts is done by using gaseous helium evaporated from the fluid helium reservoir above the resonators. The temperature of the gas leaving the cryostat is expected to be 50 K. Furthermore, this concept allows to cool down and operate the cryostat by using only liquid helium, an additional gas flow at intermediate temperature is not required. The total heat load to the radiation shield including all intercept cooling connections amounts to 75-80 W.

As the duty-cycle of the accelerator was expected to be only 0.1 %, particularly the static losses of the cryogenic system were minimized, leading to the values listed in table 2.

Table 2: Expected heat losses at 4 K for one cryomodule.

RF losses	3 W
Input coupler	2 W
Vacuum cold-warm transitions	0.45 W
Tuner	0.9 W
Cavity support	0.95 W
Thermal radiation	0.7 W
Total heat load	8 W

Cavity Alignment

First beam dynamics simulations stated the need for tolerances below +/- 250 µm. A careful estimation taking into account all fabrication steps (given in tab. 3) showed that this requirement is not feasible. Further calculations will assume a cavity to cavity tolerance of +/- 560 µm, while the accuracy between the 4 cavities and the beam axis will be 300 µm. Each cavity will have a reference surface to minimize the cavity to cavity error, while the position of the girder can be adjusted via the top flange. The control of the cavity positions will be done optically using an alignment port parallel to the beam axis. Here, the resonator positions can be viewed even in the cold state. Using this to correct the cavities positions, the final alignment is expected to be better than the value given in tab. 3.

Table 3: Worst case alignment deviations and their contributions.

Cavity fabrication accuracy	240 µm
Girder fabrication accuracy	100 µm
Girder load strain	100 µm
Girder cool down deformation	100 µm
Cryostat fabrication accuracy	200 µm
Cryostat positioning	100 µm
Total accuracy	840 µm

RF POWER COUPLER

The design of the cryostat had favoured a coupler mounted at the lid flange of the cryostat. Several different coupling and mounting positions had been analysed taking into consideration the possibility of an adjustable coupling. A capacitive coupling to one of the top access ports of the cavity is not possible due to the high power losses (some 100W). An additional coupler port will restrict the adjustability of the coupling strength and increase the cost for the cavity and the cryostat.

We found an inductive coupling with two ceramics windows to be the most favourable solution. The coupler line contains the cryostat-shielding vacuum; it is interfaced to the air by a warm ceramic coaxial window and to the cavity vacuum by a ceramic vase at lHe temperature. The coupler will transmit the output power of 4kW by the foreseen transistor amplifiers [4] to the upper short plate of the coaxial accelerating resonator. The copper loop will be cooled to about 80K to provide small thermal radiation to the superconducting accelerating cavity.

The first prototype of the RF main coupler was built and first tests have been carried out. The coupling is mainly inductive and is adjustable to get a loaded Q of 10^6 to 10^9. The vacuum transmission line down to the loop has a bandwidth of 0 to 1GHz. This allows the use as input coupler at both accelerating frequencies (160MHz and 320 MHz) and as output coupler of higher-harmonic components induced by the beam bunches. The Fourier transform of the time domain measurement between 0.045 – 2 GHz shows the frequency response of the coaxial window part (Fig. 3).

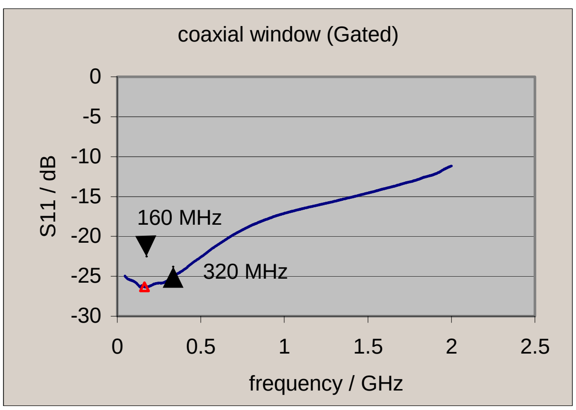

Figure 3: Fourier transform of gated time domain measurement of RF coupler.

The recent parameters are given in tab. 4, while the basic layout is shown in fig. 4.

Table 4: RF, mechanical and thermal parameters of the main coupler.

	160 MHz	320 MHz
Cavity Q by coupler	Adjustable 1E6-1E9	
Height of cold window-cavity vertex	1mm	7,5mm
Length in cryostat	~ 600mm	~ 600mm
Adjustable length	+/- 25mm	+/- 25mm
Outer diameter of cold window	28mm	28mm
Ceramic material	F99,7 (HF)	F99,7(HF)
Pk. mag. cavity field B_p	80mT	80mT
Vase tang. E field at B_p	310kV/m	310kV/m
Vase rad. E field at B_p	250kV/m	250kV/m
Vase tang. B field at B_p	35mT	35mT
RF pk. power, 100%refl.	4kW	4kW
Aver. power, 100%refl.	80W	80W
Char. Impedance	50 Ohm	50 Ohm
RF attenuation, 0% refl.	0,005 dB	0,01 dB
Eff. loop area @ vase vertex	0,9 cm²	0,9 cm²
Temp. of coupling loop	80K	95K
RF loss near 300K	~ 1,5W	~ 2,5W
RF loss near 80K	~ 0,7 W	~ 1,4 W
RF loss near 4K	~ 0,1 W	~ 0,18 W
Temp. of cold window	8K	12K
Therm. conduction to 60K	500mW	500mW
Cond.+rad. Pwr. To 4K	80mW	95mW

The vase will keep abrased dust away from the cavity. So four couplers can be mounted at the top flange of each cryostat; that simplifies its design. Thin layers of semi-insulating Ge evaporated on both surfaces of a vase and recrystallized will avoid electrostatic discharges. Figure 1 shows the mechanical dimensions and Table 3 the main parameters.

The warm coaxial window is sealed by Vacodil rings plated of 5 micrometer of copper. The outer ceramic surface will be rinsed by air to remove static charges

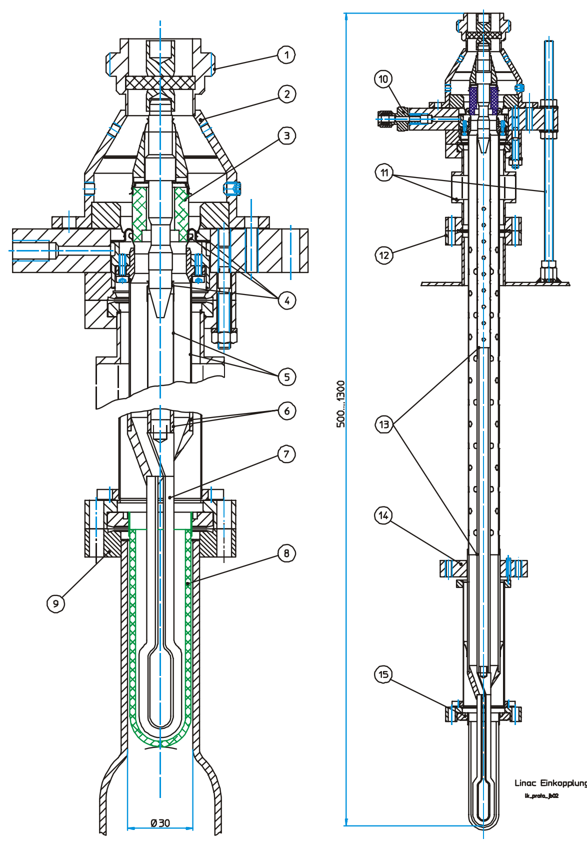

Figure 4: Lay-out and details of the RF power coupler. (1) 13/30 connector, (2) conical line with tuning screws, (3) coaxial ceramics, (4) contact springs transition lines, (5) steel-tube line + 10 micrometer Cu, (6) OFHC Cu coax line, (7) OFHC Cu loop and (8) ceramic vase, (9) CF40 flange of Nb cavity, (10)air rinsing, (11) bellows and arresting unit, (12) CF cyrostat flange, (13) Cu/steel interfaces, (14) 80K connector, (15) vase flange (Ti).

TUNER

The development of a tuning system for the HWR includes both a fast piezoelectric tuner and a mechanical tuning system. It has to perform several functions: to compensate for the changes of frequency due to pressure and temperature fluctuations as well as due to Lorenz-force detuning. In addition, the tuning system has to bring the cavity to resonance after installation and cooling down as well as to detune the cavity in case of failing.

- tuning sensitivity of cavity: 100 kHz per mm
- detuning range due to the Lorenz force: about 100 Hz
- mechanical pre-adjustment: ± 2 mm
- gear ratio stepping motor/piezo to cavity: 1:6
- slow tuning range ±0.3 … ±0.6 mm by stepping motor (depending on the value of elastic deformation)
- slow tuning steps of 2 µm (200 Hz) by stepping motor
- fast tuning range 9 … 18 µm (900 … 1800 Hz) by piezo
- materials: titanium and stainless steel (316L)

The tuning system is mainly composed of two parts, the stepping motor including the gear unit and three piezoelectric elements and the mechanical mechanism (Fig. 5). The whole drive unit is located outside the cryostat at ambient temperature whereas the mechanical part is located inside at cold temperature.

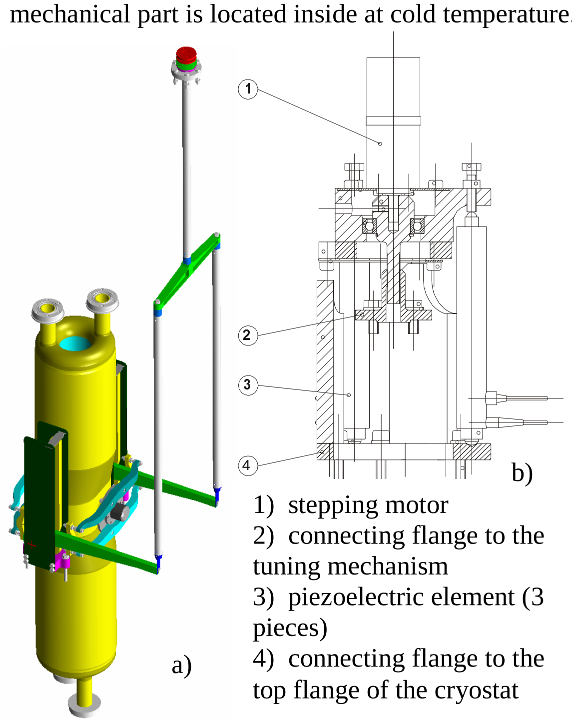

Figure 5: a) tuning system and b) drive unit of the tuning system.

The tuning motion is brought to the cavity through an arrangement of rods vertical to the beam axis from the top flange of the cryostat. They lead to two levers, one at each side of the cavity. The levers change the vertical motion into a motion parallel to the beam axis using only elastic deformation of the components. The main strain is then located in a torsion tube.

The calculated stress and deformation of the cavity are shown in Fig. 6.

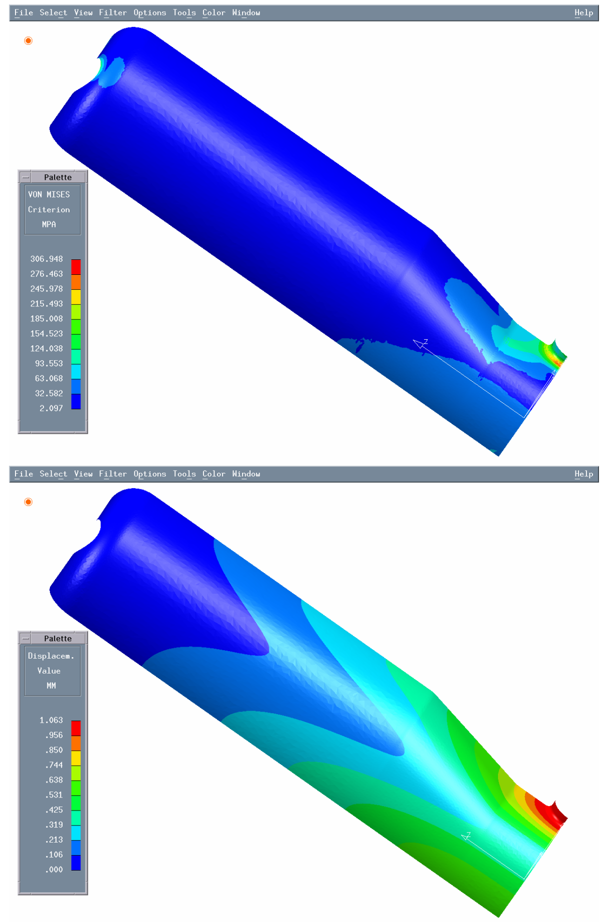

Figure 6: Calculated stress and displacement during the tuning process.

One complete tuning system for the vertical test-cryostat is still under construction and the first measurements in a test unit are expected in November this year.

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