COMPARATIVE DESIGN STUDIES OF A SUPER BUNCHER FOR THE 72 MEV INJECTION LINE OF THE PSI MAIN CYCLOTRON

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Abstract

The envisaged current upgrade from 2 to 3 mA of the PSI 590-MeV main cyclotron requires an increase of the global accelerating voltage of the 50-MHz cavities which leads to a nearly unacceptable RF requirement for the 150-MHz flat-top cavity. In order to preserve the transmission of the machine while relaxing the high demands on the flat-top system, it is conceivable to install a buncher in the 72-MeV injection line. To this end, normal-conducting 150-MHz half-wave resonators and 500-MHz two-gap drift-tube cavities have been designed and optimized for minimum input power and peak surface fields. The dependence of the RF properties (Q_0, shunt impedances and peak fields) with beam apertures and gap voltages compatible with beam-dynamics requirements are presented.

INTRODUCTION

Used as a driver for the Swiss spallation neutron source (SINQ), the PSI cyclotron facility consists of the 72-MeV injector cyclotron (Injector 2) and the 590-MeV main ring cyclotron. Injector 2, with two double-gap 50-MHz RF cavities and two smaller 150-MHz cavities, can accelerate and extract a 2.2 mA proton beam. The beam bunches are injected into the ring cyclotron through a 58 m long transport line (96 mm diameter). The main cyclotron, which is equipped with four 50-MHz cavities and one 150-MHz flat-top cavity, routinely extract 1.8 mA and stable operation at 2 mA has been demonstrated last year.

Upgrading the 2 mA beam current to 3 mA brings new challenges [1]: higher accelerating voltages and power amplifiers capable of handling large RF power swings are required to mitigate the beam loading and space charge effects. Moreover, the cavities of the main cyclotron are already operating close to their thermal limits. A rebuncher installed in the transfer line would considerably relax the RF requirements of the main cyclotron cavities leading, at best, to the decommissioning of the 150-MHz flat-top cavity.

The first type of rebuncher that has been investigated is a 150-MHz normal-conducting coaxial half-wave resonator. Whereas coaxial quarter-wave resonators are preferentially used at reduced velocity β lower than 0.3, half-wave resonators reveal themselves, at this frequency, more appropriate for β ranging from 0.15 to 0.4. The second presented option is a 500-MHz normal-conducting two-gap drift-tube cavity. This type of cavity, originally invented at Los Alamos in the mid-nineties [2], albeit used in a different context, operates in the 2π-mode and consists of an axisymmetric resonator in which a drift tube is maintained to the cavity main body by one or several stems.

150-MHZ HALF-WAVE RESONATOR DESIGN STUDIES

The half-wave resonator studies performed with the high-frequency module of ANSYS v7.1 [3] have consisted in designing several resonators with beam aperture diameters ranging from 40 mm to 96 mm and in computing their respective quality factor Q_0, shunt impedance R_{sh} and peak surface fields. The topology of the resonators (see Figure 1) was chosen as simple as possible to ease the manufacturing. The outer cylinder radius, kept constant along the cross section, was 390 mm. The two stems, on which the peak surface magnetic fields are located, were chosen to be conical to distribute the ohmic losses. The gap lengths were fixed to $\beta\lambda/8$.

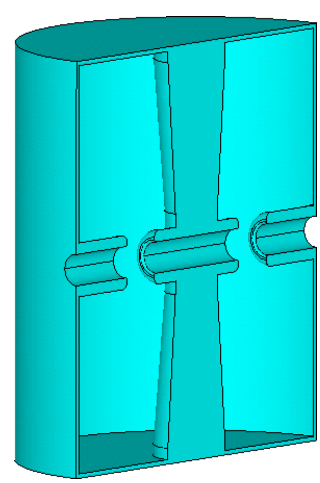

Figure 1: Cross section of the generic half-wave resonator.

The parametric studies performed on this type of half-wave resonator show a decrease of Q_0 from 27800 to 26800 as the beam aperture diameter increases (Figure 2). As for the shunt impedance R_{sh} ($R_{sh} = V_g^2/P_d$ where $V_g = \int \mid E_z(z) \mid dz$ is the total gap voltage and P_d is the dissipated power), it decreases from 15.6 MΩ to 14.1 MΩ (Figure 3). Beam dynamics simulations were performed with the particle tracking code MAD9P [4] to determine the optimum position of the rebuncher in the transfer line and the required RF voltage. Good matching at the end of the transport line is expected for an RF voltage per gap of 718 kV [5]. The computed peak surface electric fields of all the designed resonators are then lower than 19 MV/m, well under twice the Kilpatrick field. MAD9P simulations also showed that a beam aperture diameter of 50 mm is acceptable. The required RF power in this case is 132 kW (Figure 3) with a peak heat load of 22 W/cm^2. The magnetic field contour lines in this resonator are shown in Figure 4.

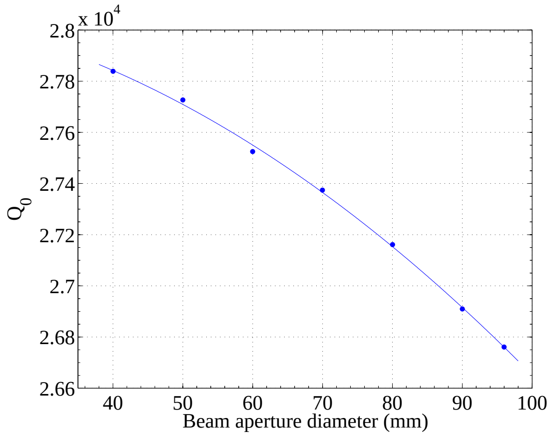

Figure 2: Half-wave resonator - Q_0 vs. beam aperture diameter.

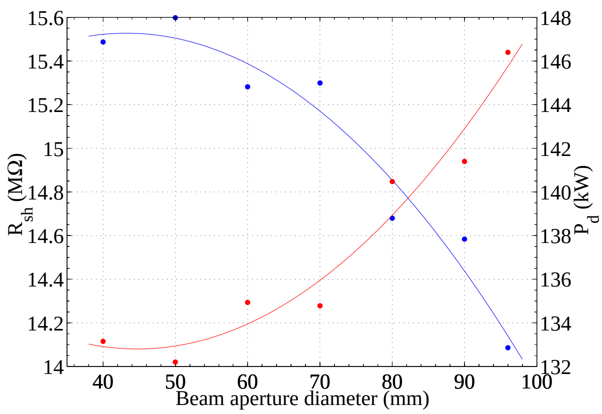

Figure 3: Half-wave resonator - R_{sh} and P_d vs. beam aperture diameter.

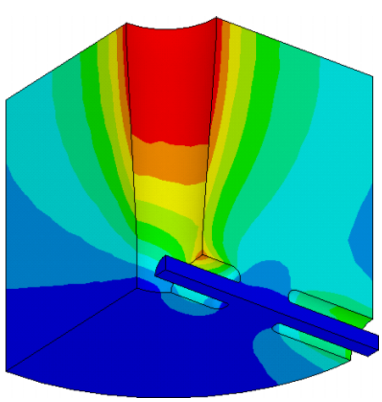

Figure 4: Magnetic field contour lines for the 50-mm beam-aperture half-wave resonator.

500-MHZ DRIFT-TUBE CAVITY DESIGN STUDIES

The design studies of a 500-MHz buncher started with the investigation of a two-gap spoke resonator [6]. For a cavity with a 70-mm beam aperture, the highest shunt impedance obtained was 3.5 MΩ. A TM-class resonator, a system of two axisymmetric nose-coned cavities inductively coupled via four azimuthal slots cut in their common wall and operating in the π-mode, has also been studied. The best achieved shunt impedance was 5.1 MΩ, also with a 70-mm beam aperture.

These unfruitful attempts led us to investigate two-gap drift-tube cavities (see Figure 5). These resonators were first optimized with the CDTfish tuning module of the 2D electromagnetic code SUPERFISH [7]. They were then retuned with ANSYS v.7.1 by adjusting their outer diameter to correct the frequency shift induced by the two cylindrical stems. For beam aperture diameters between 50 mm and 96 mm, the gap lengths were fixed to $0.3\beta\lambda$. For smaller apertures, the profile of the longitudinal electric field on the beam axis is double pecked. The gap lengths were then reduced to $0.25\beta\lambda$ for the 40 mm aperture case. The diameter of both stems was 20 mm. The angles associated with the nose cones of the cavity outer wall and the tips of the drift tube were kept constant to 20 ^{o}. The curvature radii of the tips at the level of the gaps were fixed to 2 mm.

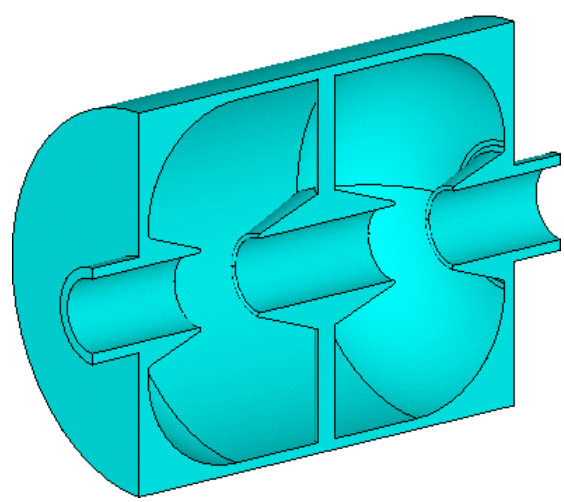

Figure 5: Cross section of the generic drift-tube cavity.

For beam aperture diameters ranging from 50 mm to 96 mm, Q_0 decrease from about 36000 to 31000 (Figure 6), values substantially higher than those obtained for the half-wave resonators. The shunt impedances are also much higher, decreasing from 26.3 MΩ to 16.3 MΩ (Figure 7). In the 40 mm aperture case, with slightly reduced gap lengths, the shunt impedance is nearly the same than in the 50 mm case.

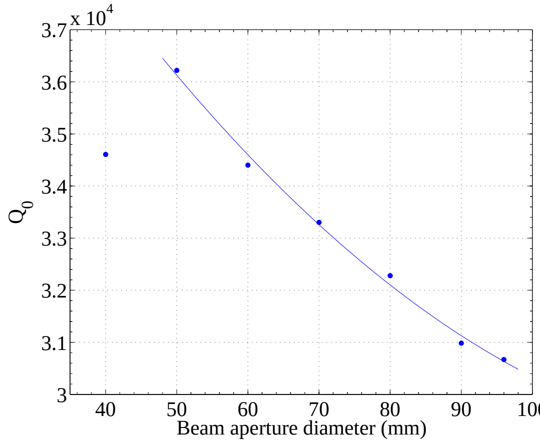

Figure 6: Drift-tube cavity - Q_0 vs. beam aperture diameter.

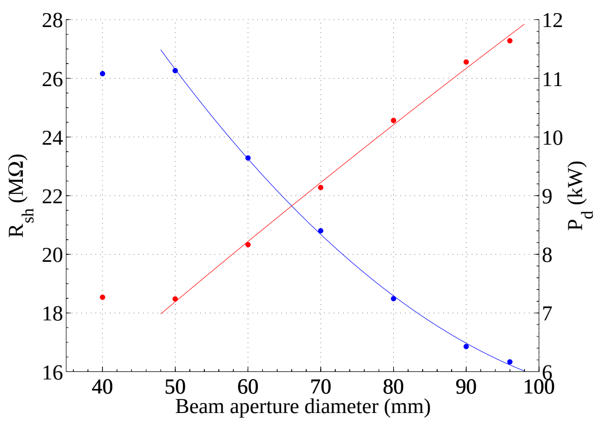

Figure 7: Drift-tube cavity - R_{sh} and P_d vs. beam aperture diameter.

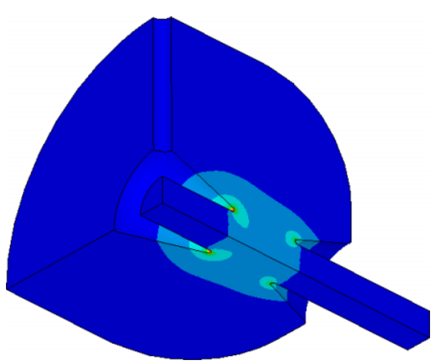

Figure 8: Electric field contour lines for the 50-mm beam-aperture drift-tube cavity.

The required RF voltage per gap, computed with MAD9P, is 218 kV [5]. For the drift-tube cavity with a 50 mm beam aperture, the needed RF power is about 7 kW (Figure 7), more than one order of magnitude less than the RF power needed to drive the half-wave resonator. The peak surface electric field is lower than the Kilpatrick field (see Figure 8 for the electric field contour lines) and the peak heat load, located at the junction of the drift tube with the stems, is 12 W/cm^2. The magnetic field contour lines of this resonator are shown in Figure 9.

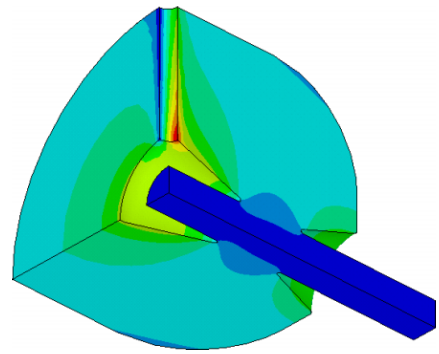

Figure 9: Magnetic field contour lines for the 50-mm beam-aperture drift-tube cavity.

CONCLUSIONS AND OUTLOOK

Among the presented options, the 500-MHz drift-tube cavity with a beam aperture diameter of 50 mm is the most satisfying type of resonator with regards to power requirements, peak surface electric fields and maximum heat load. However, preliminary beam simulations revealed the presence of some non-linear RF effects [5] that may have deleterious consequences on the bunch dynamics in the main cyclotron.

A drift-tube cavity prototype is at present under study with a special attention paid to the design of the cooling channels in the drift tube, the peak heat flux being at the connection of this element with the stems. The design of the power coupler and of the tuning system is under way as well.

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