DESIGN OF RF-CAVITIES FOR CW OPERATION [1]

Frank L. Krawczyk, Nathan K. Bultman, K.C. Dominic Chan, and Rick L. Martineau
AOT-1, MS H817, Los Alamos National Laboratory, Los Alamos, NM 87544, USA

Abstract

Funnels are a key component of accelerators proposed for transmutation technologies. In addition to conventional accelerator elements, specialized rf-cavities are needed in a funnel. Simulations were done to obtain their electromagnetic field distribution and to minimize the rf-induced heat loads. Using these results a structural and thermal analysis of these cavities was performed to insure their reliability at high average power and to determine their cooling requirements.

Introduction

High intensity CW proton accelerators are proposed candidates as drivers for waste transformation systems and spallation neutron sources. An essential component of such accelerators is a funnel. In a funnel two beams are merged into a single beam. This is accomplished by using an arrangement of lenses and special rf-cavities [1]. An example is the recent design of the Accelerator Performance Demonstration Facility (APDF) in Los Alamos[2]. The design of the APDF funnel's special deflector and buncher cavities will be discussed here.

For the electromagnetic analysis preliminary calculations [3] have been done with the 2D code SUPERFISH. As these cavities are not axi-symmetric, the required final 3D modeling has been done using the finite difference electromagnetic program package MAFIA (Rel 3.2 [4]). The estimated parameters from the 2D-calculations were the starting point for this analysis to determine the final shapes and sizes that should yield structures with reasonable wall losses and the desired operational frequencies. Besides the 3D capabilities MAFIA has a flexible input language allowing a variable description of grid and structures. This significantly simplifies the parameter studies to tune and optimize these structures. Also the extended postprocessing helped to easily evaluate secondary quantities like wall losses for the appropriately normalized field solutions. For the transfer of loss data to the structural analysis code an interface has been programmed [5] within the MAFIA code.

The structural analysis has been done with the finite element code ABAQUS (V5.3). The heat flux data provided by the MAFIA code was used as a boundary heat source condition on the finite element model. This data was imposed on the finite element mesh by using the closest element surface to a MAFIA output point. This produced a very good mapping between the the two differently discretized models.

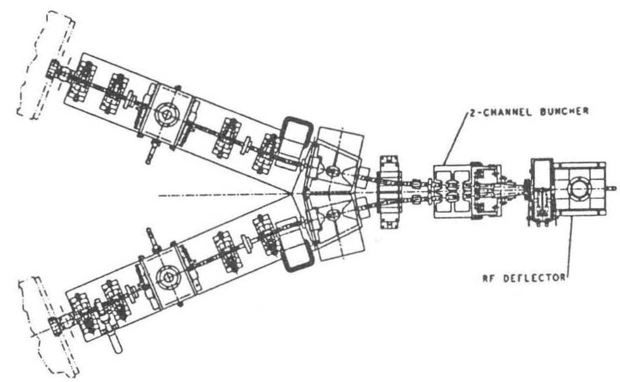

Fig. 1. This plot shows the front-end part of the APDF. The beams from the two ion-sources are deflected into a common channel. The two cavities of the final step of the deflection will be discussed here.

The Deflector Cavity

In the funnel the beams from the two ion-sources are combined into a single beam by deflection. To conserve the beam quality this deflection has to be done in several steps. The final deflection needs a common optical element for both channels, since they already are very close to each other. Static electric or magnetic fields cannot be switched or reversed fast enough to provide both beams with the needed change in momentum, thus use of a rf-field has been proposed. The deflector geometry has to provide a harmonic electric field orthogonal to the beam direction for opposite deflections acting on each beam.

Figure 2 shows the model of a deflector cavity that is crossed radially by the two beams. They are

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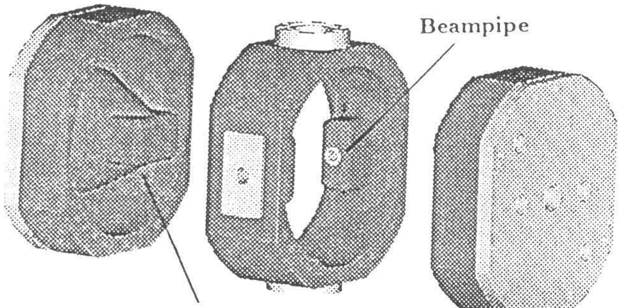

Fig. 2. This is the structural model of a deflector cavity. The end caps hold the electrodes fixed to circular cones. The central ring holds the noses housing the common beam pipe.

guided close to the electrodes by a beam pipe sitting inside a rectangular metal nose. The electrodes sit on top of cylindrical cones aligned with the cavity's cylinder axis. The cavity's fundamental mode with a dominant electric field between the two electrodes deflects the beams when they pass the electrodes. The shape of the electrodes as well as the electrode distance have been chosen to provide a homogeneous field where the beam passes them. It is practically constant ($\Delta E_z < 0.5\%$) in a transverse range ± 10 mm around the central axis.

Calculations show that a gap longer than $\beta\lambda/2$, despite a partial compensation of the achieved deflection, allows a lower overall field level in the cavity than a shorter gap of $\beta\lambda/2$. This arrangement would result in a less effective deflection that requires a higher field amplitude.

The tuning of the cavity can be done by changing the cavity radius or the radius of the base of the circular cones holding the electrodes. A combination of these two parameters has to be found that yields the desired frequency and low heat loads. Our final model is not necessarily the optimal one. We just searched for a parameter set that reduced the losses to a tolerable level and fits the tight longitudinal space requirements at the deflector position of the accelerator. Table 1 shows some of the calculated loss information of the APDF deflector at 350 MHz for a peak gap-field of 24 MV/m.

TABLE 1
Loss information on the deflector cavity

Total Loss	Peak Loss Density
48 kW	68 W/cm^2

The loss data from the numerical field calculation have been transferred to ABAQUS for the stress and thermal analysis described in the next section. From the structural analysis the change of gap-height has been determined as the dominant deformation of the structure. With MAFIA the resulting detuning that can be expected for this cavity has been estimated to be small.

The Thermal Analysis of the Deflector Cavity

The thermal analysis for the deflector to date has been limited to the nose region of the electrode. The heating varies considerably around the circumference of the electrode. Taking this into account a cooling scheme has been chosen that provides enhanced cooling along the sides of the rectangular electrodes. The analysis

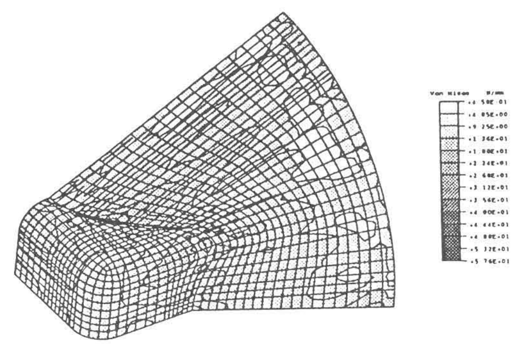

Fig. 3. The Von Mises stresses for the heat loads calculated with MAFIA and the provided cooling.

predicts a peak temperature of 63 C; this is a rise above inlet water temperature of 43 C. Peak stresses (figure 3) are predicted to be 58 MPa, or about 85% of the copper yield stress. This is adequate for this stage of the design effort; use of additional cooling will be investigated during the detailed design phase.

The Two Beam Buncher

The rf-deflection scheme requires short bunches so that they will not experience different deflections at head, center and tail due to the harmonic change in the deflecting field amplitude. To minimize this effect bunches have to be longitudinally compressed shortly before entering the deflector. As the two beams are already very close at this point they need a common buncher cavity. To reduce the peak electric surface fields for each channel two bunching gaps have been chosen within a single cavity. This also significantly reduces the wall-losses.

The two beams enter the circular cavity tank with angles less than approximately ±2 degree to the cylindrical axis. The gaps for each beam are defined by half drift tubes attached to the end walls and a central drift tube held by a circular stem. The cavity is operated in a zero-mode at twice the deflector frequency. The distance between the two gaps is $\beta\lambda$, thus the particles see the same bunching in both gaps.

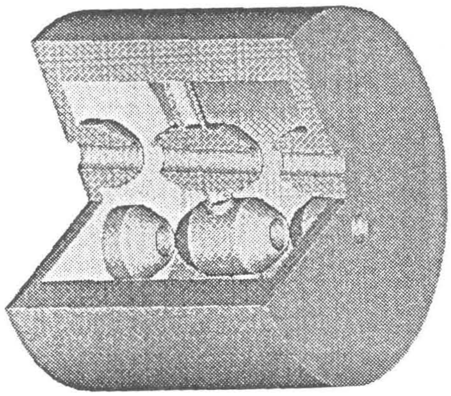

Fig. 4. This is a structural model of the two beam buncher cavity. The strong bunching is achieved by using two gaps within a single cavity.

The cavity was tuned to the desired frequency of 700 MHz and the induced wall-losses for the mode of interest were determined. The tuning parameters were the radius of the cavity tank and the length of free space between the drift tubes. This length was chosen to minimize the peak electric fields necessary to achieve the desired E_0TL. The cavity radius should be as big as possible to reduce the wall losses. Here again losses were only reduced to a tolerable level. Table 2 lists the cavity losses for a field achieving an E_0TL of 0.472 MV.

Table 2
Losses on the Two Beam Buncher Tubes

Total Loss	Pk. Loss Density	Average Loss
45 kW	220 W/cm^2	100 W/cm^2

The Thermal Analysis of the Two Beam Buncher

In the two beam buncher the surface heating is highest near the drift tube stem and body junction on the surface of the drift tube, where the heat flux is about 220 W/cm^2. The heating drops to near zero on the tube body opposite from the stem joint, at the point closest to the drift tube of the neighboring channel. Cooling for the central tubes is provides through the circular stem. This puts cooling water in close contact with the highly heated regions and provides good thermal control. In addition there is substantial circumferential heat flow in the wall of the drift tubes due to the high thermal conductivity of the copper. These two factors smooth the thermal peak near the stem joints and redistribute the energy flow in the tube body away from the purely one-dimensional situation. Considering the heat loads and the proposed cooling the analysis shows a temperature rise above the coolant inlet temperature of about 30 C; this coupled with the pressure stress of the water gives a peak stress in the drift tube surface of about 33 MPa, half the yield strength of annealed copper. This is adequate for the service anticipated.

Outlook

These simulations indicate that the special cavities required in the funnel-section of such a high-current accelerator can be reasonably controlled.

The field distribution in both cavities is asymmetric with respect to the beam channel axes producing a strongly position dependant surface heating. The ABAQUS evaluation to date has been done only for the most critical parts of the structures. An evaluation for the full structure will follow.

For the detailed design phase of the APDF adjustments could be done to further improve the thermal behavior. In particular, the deflector cavity could be modified to reduce the stresses expected in the electrodes in the present design.

An interfacing between electromagnetic and structural codes has proven important for a successful design of high power rf-structures.

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