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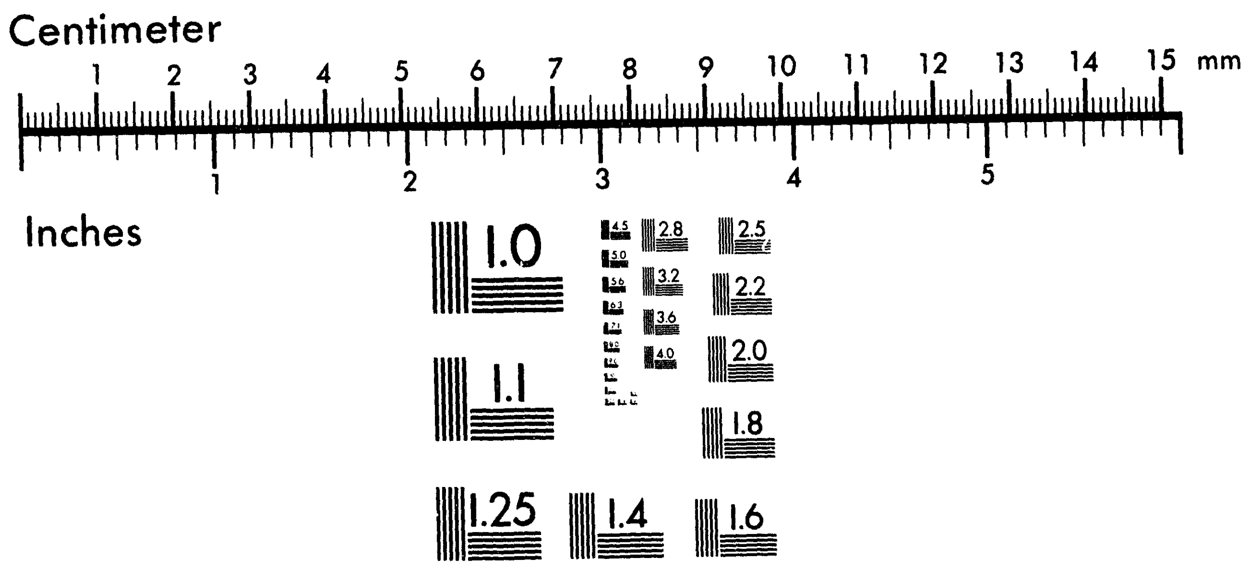

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TITLE: DESIGN OF RF-CAVITIES IN THE FUNNEL OF ACCELERATORS FOR TRANSMUTATION TECHNOLOGIES

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Design of RF-Cavities in the Funnel of Accelerators for Transmutation Technologies[1]

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Abstract. Funnels are a key component of accelerator structures proposed for transmutation technologies. In addition to conventional accelerator elements, specialized rf-cavities are needed for these structures. 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. For one cavity the thermal expansion data in return was used to estimate the thermal detuning.

INTRODUCTION

High intensity CW proton accelerators are proposed candidates as drivers for waste transformation systems and spallation neutron sources. An essential component of such a structure 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 in Los Alamos[2] (APDF). The design of the APDF funnel's special deflector and buncher cavities will be discussed here.

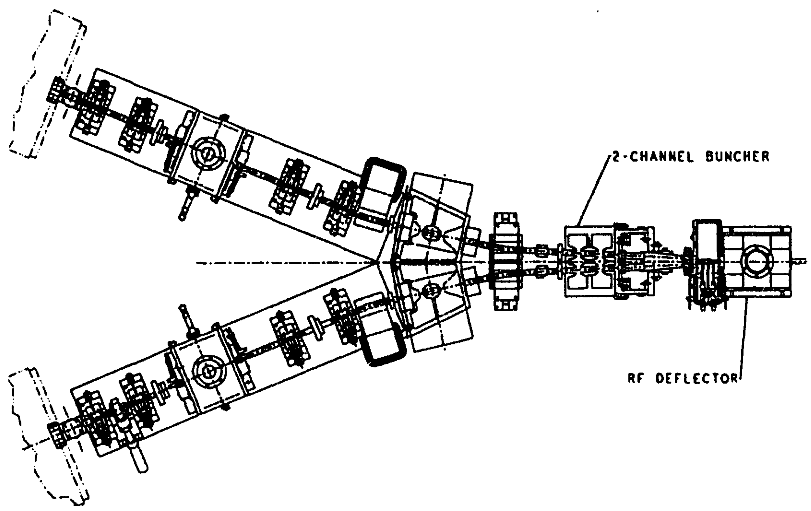

Fig. 1. This plot shows the front-end part of the APDF. The beams from the two ion-sources are deflected into a common channel. The deflector and two-beam buncher cavity for the final step of the deflection will be discussed here.

For the electromagnetic analysis preliminary calculations have been done with the 2D code SUPERFISH [3]. As these cavities are not axis-symmetric, their final modeling requires a 3D-analysis. The estimated parameters from the 2D-calculations were the starting point for

[1]Work supported by Defense Nuclear Agency

this analysis to determine their final shapes and measurements that should yield structures with reasonable wall losses and the desired operational frequencies. These simulations have been done using the finite difference electromagnetic program package MAFIA (Rel 3.2 [4]). 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 post-processing helped to easily evaluate secondary quantities like wall losses, Q and shuntimpedance for the appropriately normalized field solutions. For the transfer of loss data to the structural analysis code command macros and an interface have been programmed [5] within the MAFIA code.

The structural analysis has been done with ABAQUS (V5.3), a finite element code. 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.

Despite the necessity to do a final 3D-modeling it is remarkable that already the 2D-calculations gave good approximations of the final structures. For example, the estimated deflector gap voltage (24MV/m) derived from these calculations agreed within $< 1\%$ with the one derived from the 3D-model. The modeling process for this parameter study has been significantly accelerated by the preliminary 2D-calculations.

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

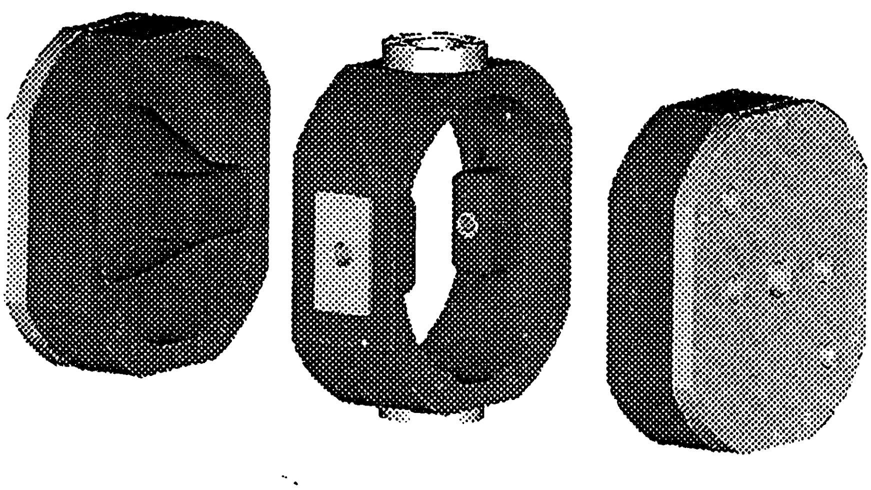

Fig. 2. This is the structural model of a deflector cavity. The end caps hold the electrodes fixed to circular cones. The central ring holds the noses housing the common beam pipe.

final deflection has to be done by the same 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. The fastest method is a rf-field, whose frequency is an odd multiple of half the bunch repetition rate. The deflector geometry has to be chosen to have a harmonic electric field orthogonal to the beam direction providing the opposite deflections for each of the two beams. Figure 2 shows the model of such a deflector cavity.

The beams cross the cylindrical cavity radially, not on the cylinder axis. They are 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 electric field of the cavity's fundamental mode with a dominant amplitude between the two electrodes, normal to the beam directions, deflects the beams when they pass the gap between the electrodes.

The rectangular shape of the electrodes as well as the electrode distance have been chosen to provide a fairly 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. Any arrangement with a shorter electrode results in a less effective deflection that requires an even higher field amplitude. For a final deflection of 1.9 degree the APDF deflector cavity needs a deflection of 2.02 degree associated with the passage between the two electrodes.

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 the lowest possible 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. The APDF deflector cavity has a radius of 121 mm. The cone base radius is 73.5 mm. Table 1 shows some of its calculated properties for a peak gap-field of 24 MV/m.

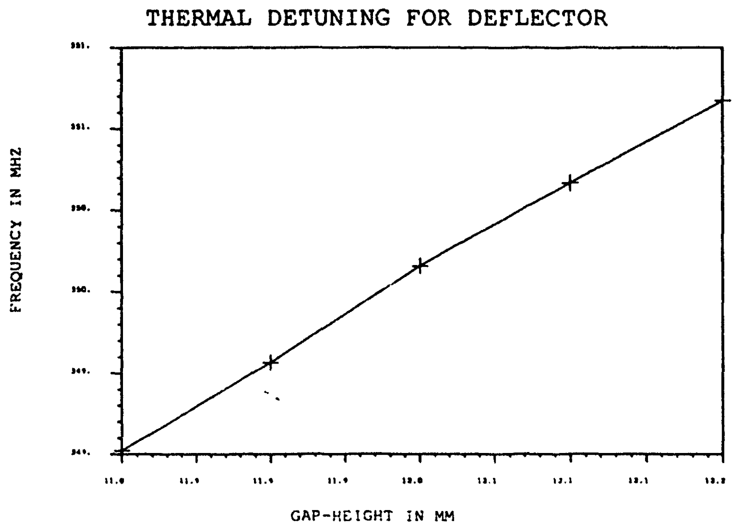

Fig. 3. Here the frequency variation for an assumed gap height variation due to thermal expansion is displayed. The change seems to be linear. For a gap variation of ± 2 mm the frequency changes by only $\pm 0.3\%$.

Table 1. Important Parameters of the Deflector Cavity

Frequency	Integrated Loss	Peak Loss Density	Deflection Angle
350 MHz	48 kW	68 W/cm^2	1.9 deg

The loss data from the numerical field calculation have been transferred to ABAQUS for the stress and thermal analysis. This analysis will be described in the next section. From the stress analysis the change of gap-height has been determined as the dominant deformation of the structure. With the electromagnetic field calculation program the resulting detuning that can be expected for this cavity has been estimated (see figure 3).

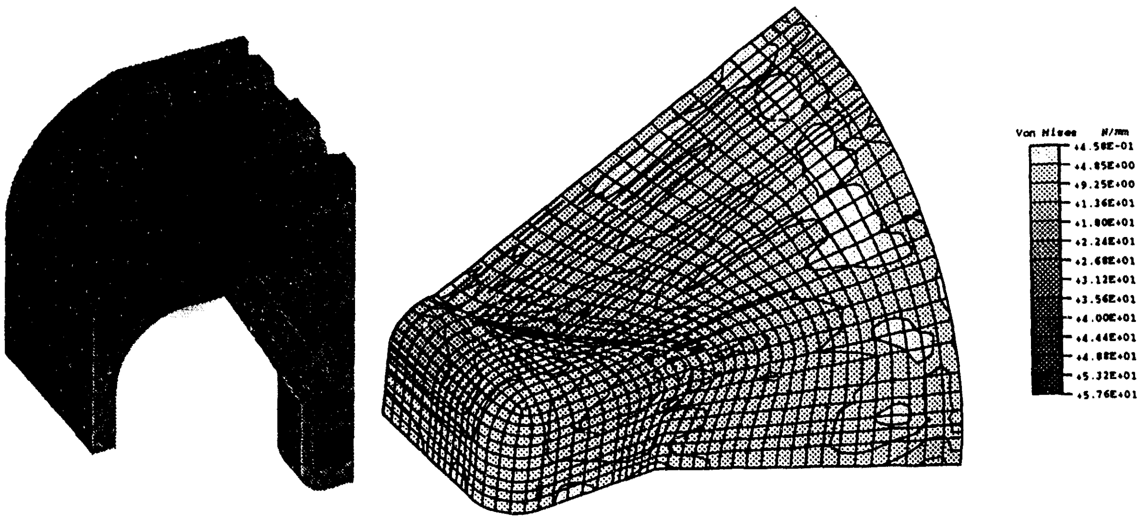

Fig. 4. Left the cooling passages in the deflector electrode are shown. They provide an adequate cooling for the heat loads predicted by the MAFIA field calculations. The right part shows the Von Mises stresses taking into account the heat loads and the cooling provided.

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. The left part of figure 4 shows a cut-away of the cone region and the location of the cooling passages drilled into the wall of the cone. Cooling water flows into the end cap of the cavity and through the the drilled passages in the cone wall. It then flows across the surface and end of the deflector electrode and returns through the center of the cone. The analysis predicts a peak temperature of 63 C, this is a rise above inlet water temperature of 43 C. Peak stresses (right part of figure 4) are predicted to be 58 MPa, or about 85% of the yield stress. This is adequate for this stage of the design effort; probably additional cooling will be required and will be added during the overall detailed design phase.

THE TWO BEAM BUNCHER

There is one disadvantage of the rf-deflection scheme. Bunches not short enough will experience different deflections at head, center and tail due to the harmonic change in the electric 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. Also for very short bunches a single buncher would need an unreasonably high field level. To reduce the needed amplitude two buncher cavities can be used. Since these in cw-operation still dissipate a huge amount of power, a combined two beam and double gap buncher (figure 5) has been proposed. As this double gap structure has two endwalls less than two single buncher cavities, this arrangement has significantly reduced wall losses.

The two beams enter the circular cavity tank under angles of approximately ±2 degree symmetric to the cylindrical axis. The gaps for each beam are defined by two half drift tubes attached to the end walls and a central drift tube held by a circular stem. The cavity is

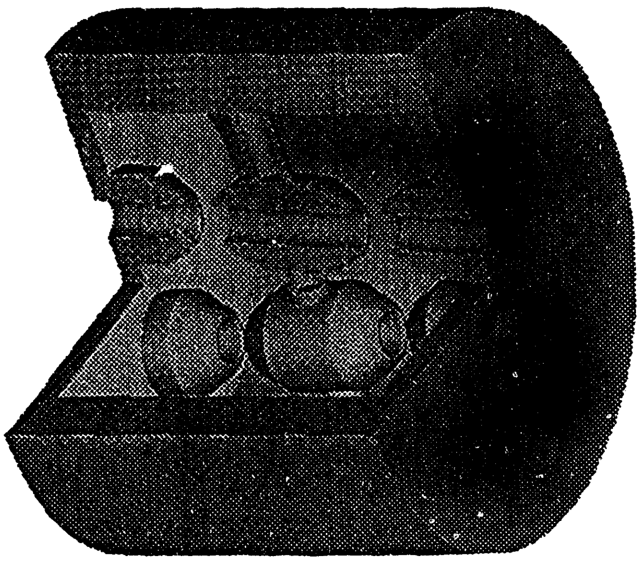

Fig. 5. This is a structural model of the two beam buncher cavity. The strong bunching required for the deflector is achieved by using two gaps within this cavity. This reduces wall losses significantly compared to a single gap or two single gap cavities.

operated in the mode shown in figure 6 at twice the frequency of the deflector. The distance between the two gaps is $\beta\lambda$, thus the particles see the same bunching in both gaps.

The electromagnetic field calculations were used to tune the cavity to the desired frequency and to find the induced wall losses for the mode of interest. The tuning parameters were the radius of the cavity tank and the length of free space between the drift tubes. The length of free space was chosen long enough to minimize the electric peak fields necessary to achieve the desired E_0T. The cavity radius should be as big as possible to reduce the wall losses. Here again not the optimal cavity was designed. Losses were only reduced to a tolerable level. The following table includes some of the calculated cavity properties for a field achieving an E_0TL of 0.472 MV.

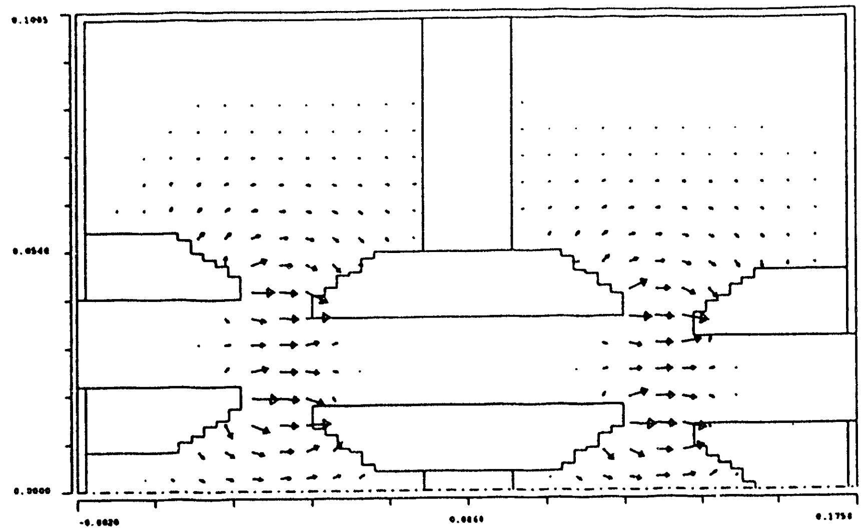

Fig. 6. This mode is used for bunching. The plot shows the electric field in one of the symmetry planes. The frequency of this mode is twice the frequency of the deflector following this cavity.

Table 2. Important Parameters of the Two Beam Buncher

Frequency	Integrated Loss	Peak Loss Density	Average Loss on Tubes
700 MHz	45 kW	220 W/cm^2	100 W/cm^2

THE THERMAL ANALYSIS OF THE TWO BEAM BUNCHER

In the two beam buncher model the surface heating is highest near the drift tube stem and body junction on the surface of the drift tube, here the heat flux is about 220 W/cm^2. The heating drops to near zero on the tube body at a location 180 degree from the stem joint, at the point closest to the drift tube of the neighboring channel. Cooling water flows in through the stem on one side of the buncher cavity. From there around the circumference of each drift tube in sequence and out through the stem on the opposite side. This scheme 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 tube due to the high thermal conductivity of the copper. These two factors combine to smooth the thermal peak near the stem joints and significantly redistribute the energy flow in the tube body away from a purely one-dimensional situation. In the body of the cavity simple axially drilled passages provide the cooling channels for a good and simple heat removal design. Figure 7 shows the calculated temperature contours on the drift tube body considering the heat loads and the proposed cooling. The temperature rise above the coolant inlet temperature is about 30 C; this coupled with the internal pressure stress of the water gives a peak stress in the drift tube surface of about 33 MPa, or about half the yield strength of annealed copper. This is adequate for the service anticipated.

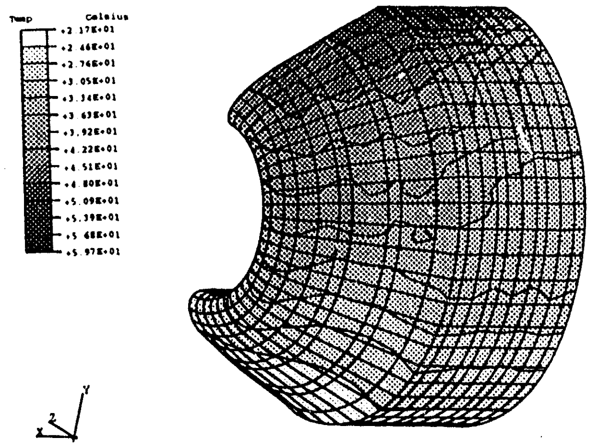

Fig. 7. Taking into account the heat loads from the magnetic field and the proposed cooling scheme described in the text the above final temperature distribution results.

OUTLOOK

These simulations indicate that the special cavities required in the funnel-section of an accelerator-driven transmutation technology can be reasonably controlled.

The internal field distribution in both cavities is very asymmetric to the beam channel axes and thus produces a strongly position dependant surface heating. The ABAQUS evaluation to date has been done only for the most critical parts of the structures. A structural evaluation for the full structure will follow.

For the detailed design phase of the APDF minor adjustments could be done to further improve the thermal behavior of the cavities. This should especially reduce the stresses expected in the electrode of the deflector from the present design.

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

REFERENCES

[1] Nath S. "Funneling in LANL High Intensity LINAC Designs", presented at this conference

[2] Chan K.C.D. "A Prototype Front-End Accelerator for Accelerator-Driven Transmutation Technologies", presented at this conference

[3] *APT Accelerator Topical Report, LA-CP-94-98* , Vol 1, Rev 1, Chap. 5, (March 94)

[4] Bartsch M. et al. "Solution of Maxwell's Equations", *Computer Physics Communications* **72** 22-39(1992)

[5] Krawczyk F.L. "Data-Transfer from MAFIA Rel3.x to other Applications as an Example for Writing Complex Applications with the MAFIA Codes", Los Alamos National Laboratory, AOT-1:94-115, (1994)

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