ADVANCED ELECTROMAGNETIC DESIGN OF CAVITIES FOR HIGH CURRENT ACCELERATORS *

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Abstract

For high-current accelerators such as those proposed for transmutation technologies or spallation sources, preconstruction numerical modeling has a high importance. Non axisymmetric cavities require a full 3-D modeling. A complex analysis of structures beyond tuning and the calculation of Q and shunt impedance is required and also the interaction with the mechanical properties of the structures has to be taken into account. This paper reports on recent work done at LANL for proposed beam funnels, a new normal-conducting medium-energy structure (CCDTL) and superconducting cavities for medium energy. The electromagnetic calculations have been done with MAFIA, Rel 3.2 [1], the thermal and stress analysis results reported come from the ABAQUS engineering code.

I. THE COUPLED-CAVITY DRIFT TUBE LINAC STRUCTURE

A. General

In the velocity range of $0.1 \leq \beta \leq 0.5$ the drift tube linac (DTL) usually is selected as accelerating cavity. Jim Billen recently proposed a new structure with high shunt impedance and a good field stability in this velocity range [2]. This coupled-cavity drift tube linac structure (CCDTL) combines features from a regular DTL and the coupled-cavity linac (CCL), a commonly used structure for high energy protons. A detailed description of the CCDTL's mode of operation is given in [2].

A major part of the cavity design (to get nose, drift-tube and cavity geometries) has been done in 2-D, neglecting the influence of stems and asymmetrically positioned coupling slots. For a study on the feasibility of the CCDTL cavity a full 3-D modeling is needed (see Fig. 1). This should yield the full mode spectrum, the expected rf wall losses, resulting mechanical stresses and the required cooling.

B. Stem Modes and Losses

The first 3-D effect investigated was the introduction of modes by the stem(s) holding the drift tubes. This was done to confirm that no stem-related modes close to the accelerating mode exist. Table 1 lists the MAFIA-calculated frequencies of the lowest stem-related modes for different relative stem positions. These have been calculated for angles between stems from 0^o (single stem) to 180^o. The frequencies far exceed the 1400 MHz of the accelerating mode. Calculations for β up to 0.5 indicate that nowhere in this range these modes pose a problem.

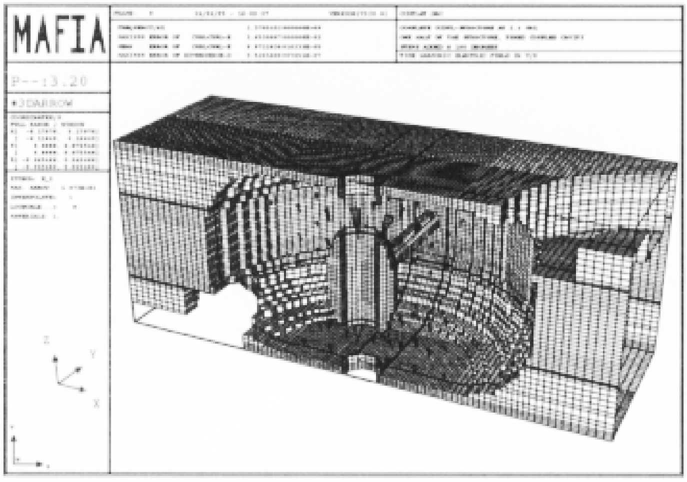

Figure 1. One half of a CCDTL structure with a single drift-tube and two stems 180^o apart (only one stem is shown) 90^o from the coupling slots. Only part of the coupling cells is shown, but full cells have been used for calculation. The cones indicate the accelerating electric field.

Table 1. Nearest Stem-Related Modes for $\beta = 0.283$.

angle (degree)	frequency [GHz]
0	2.055
60	2.090
90	2.132
120	2.161
180	2.207

The second 3-D effect investigated was the power dissipation near the CCDTL cavity's coupling slots.

Figure 2 indicates the losses due to the rf fields around one of the coupling slots. The nonsymmetric distribution of losses will be taken into account in the cooling scheme for this structure.

The different curvatures meeting at the coupling slots pose some problem for the reliable determination of peak power densities in this area. Here a recalculation of the structure with a finer mesh combined with some smoothing of the obtained loss data is necessary. This helps to distinguish between real "hot spots" in the structure and those artificially introduced by discretization errors. Such a procedure has been successfully demonstrated for the structures in beam funnels [3]. We also consider testing electromagnetic field calculation codes based on a finite element formulation, that would be more compatible with the structural analysis codes. But such codes for rf problems still have to prove their general reliability.

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* Work supported by the U.S. Department of Energy, Defense Programs

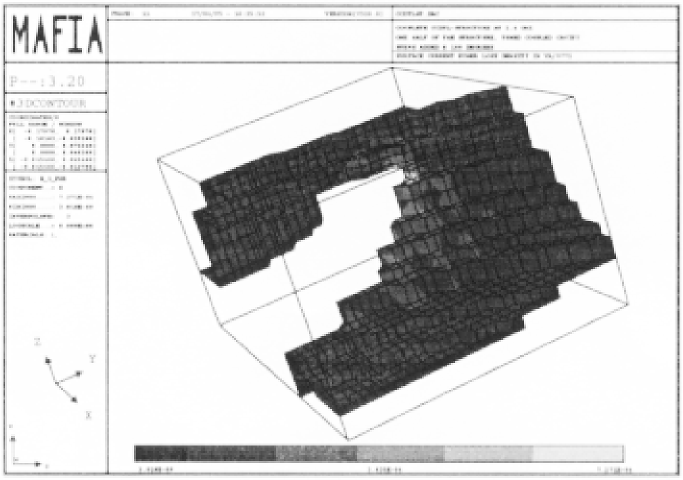

Figure 2. A close-up look at the rf-induced wall losses around one half of a coupling slot. Regions of higher losses are indicated by lighter shading.

II. DEFLECTOR CAVITIES FOR FUNNELING DEVICES

A. General

Funnels are key components of proton linacs when very high currents are required. The limits imposed by high space-charge forces at the low-energy end of a linac can be bypassed by starting with two beams of half the desired current. The bunches in these two beams from identical ion sources are formed 180^o apart. In a funnel they are merged into a single beam. This is accomplished by a suitable arrangement of conventional accelerator components like lenses and buncher cavities together with a special non-axisymmetric rf deflector cavity.

B. The Simple Deflector Cavity

The complete design of a deflector cavity (see Fig. 3) was done for the proposed Accelerator Performance Demonstration Facility (APDF) at a beam energy of 20 MeV [3]. In this design the bunch length of the protons entering the deflector was small enough to see a fairly homogeneous deflecting rf field.

The combined electromagnetic and thermal/stress analysis of the cavity indicates that such a structure can be built and operated. However, the mechanical stresses as determined from the rf wall losses seem to be challenging; the forces on the deflector electrode reach 85 % of the copper yield strength.

The choice of a funneling energy of 20 MeV was determined primarily from beam dynamics considerations. Calculations for the deflector cavity of the European Spallation Source (ESS) [4], which is designed to operate at 5-7 MeV and a 10% duty factor show significantly less thermal stress. Here we explore a design at 12 MeV to examine the possibility of reducing the thermal stress in our deflector cavity.

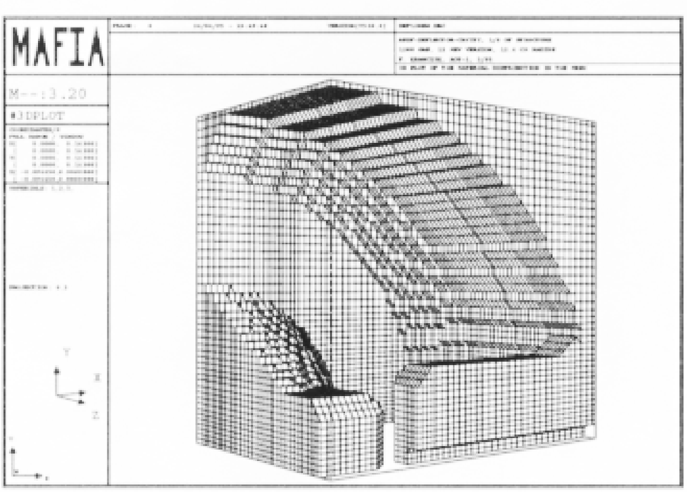

Figure 3. This is one eighths of the simple deflector cavity at 350 MHz, as modeled with MAFIA. On the left is one quarter of one of the two deflecting electrodes. On the right is one quarter of a nose-like structure, concentrating the deflecting fields near the center of the cavity.

C. The Deflector Cavity for a Combined First and Third Harmonic Deflection

At 12 MeV the longitudinal bunch size is wider than at 20 MeV. This accentuates the difference in the deflection seen by the center and the ends of the bunches. This problem can be reduced by an improved deflector cavity that uses the combined deflection of the first and third harmonic deflecting modes. If the proper phase and relative amplitude between the two modes are chosen, the temporal variation of the deflecting field will be closer to a desired rectangular deflection pulse than can be obtained with just the fundamental mode. Figure 4 shows a modified deflector that has an additional deflecting mode at 1.05 GHz. The cavity shape variation has been chosen to (1) minimally affect the fundamental mode and (2)add surfaces at locations with low magnetic field amplitude to minimize the introduction of additional wall losses. The cavity represented here is not yet optimized but already indicates a significant improvement in terms of rf losses (see Table 2).

Table 2. Comparison of Some Data for the 20 MeV and 12 MeV Deflectors

	20 MeV Cavity	12 MeV Cavity
Gap Field	24 MV/m	20 MV/m
RF-Losses	48 kW	34 kW
Peak Loss-Dens.	68 W/cm^2	60 W/cm^2

In Fig. 5 the deflecting pulses from the fundamental and the combined harmonics are compared. The combined deflection pulse stays at a high level for a longer portion of the rf period and then drops off faster than the fundamental. The third harmonic field has a phase difference of 180^o at the center of the gap and an amplitude of 1/10 with respect to the fundamental.

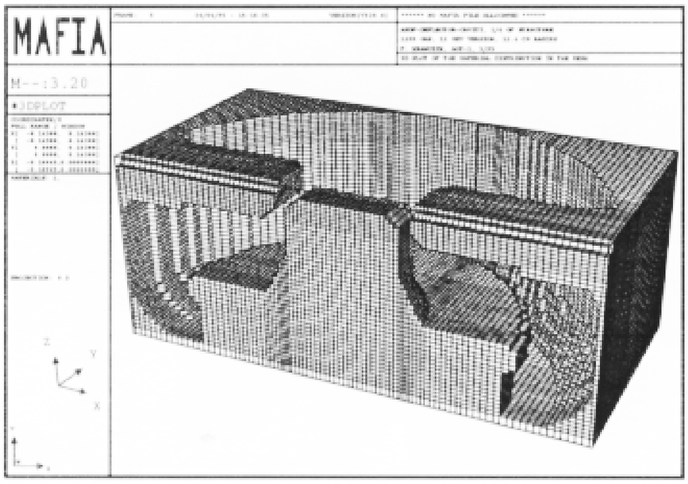

Figure 4. The combined first and third harmonic deflector. The pedestal added at the bottom of the electrodes decreases the frequency of a higher mode with a deflecting component to 1.05 GHz. The fundamental mode is hardly affected. Also the magnetic field amplitudes of the fundamental and the third harmonic in this part of the structure are low.

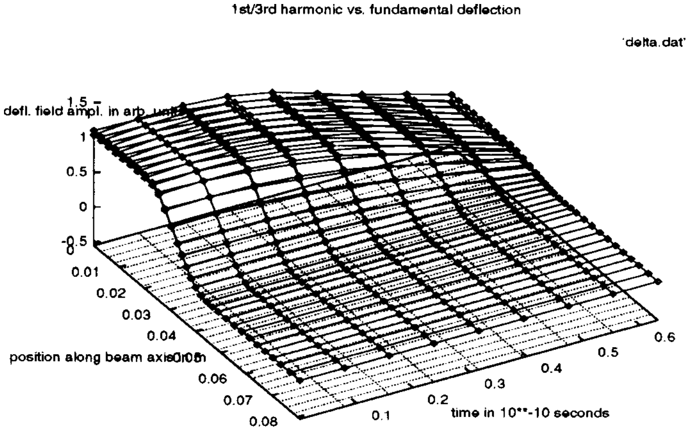

Figure 5. Comparison of the change in deflecting field with time for the fundamental and the combined deflection. The two deflecting surfaces nearly coincide, the combined deflection shows the maximal effect.

III. SUPERCONDUCTING CAVITIES FOR MEDIUM ENERGY PROTONS

A. General

Cost-saving issues in the design of high current proton accelerators raise the question of using superconducting cavities. Low risk and the need for only little technical development favor the use of elliptical cavities at high energies. At lower energies a good candidate seems to be the spoke structure, first proposed by J. Delayen et al. [5]. Figure 6 shows an eight-cell spoke cavity with a cross-bar structure at 7 MeV for 350 MHz.

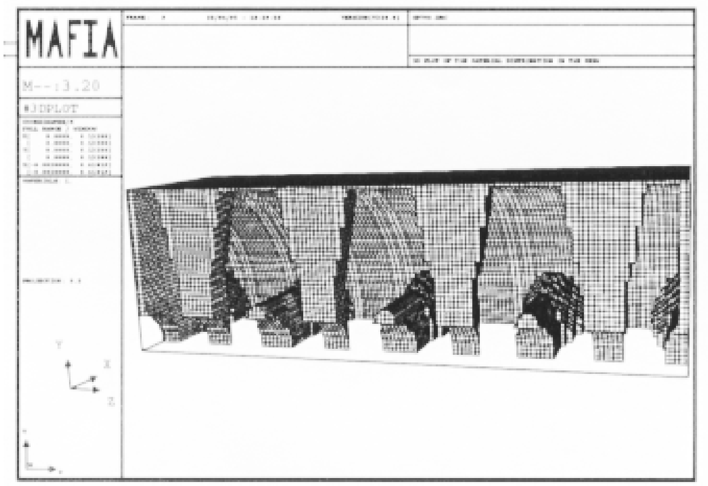

Figure 6. Eight-cell spoke cavity with cross-bar structure at 350 MHz and 7 MeV. This is one quarter of the cavity as discretized with MAFIA. The spoke shape can be further improved, but did already help to evaluate some general properties of this new structure. The beam-axis coincides with the z-axis.

This is still a non-optimized geometry that needs improvements. But it already hints that it seems suitable for several reasons:

- It has a higher mechanical stability at low β than an elliptical cavity,
- The bore size can be freely chosen, without affecting the coupling,
- The mode spectrum indicates that there are no problematic modes that should mix with the accelerating π-mode.
- It has a high ZT^2/Q ($800\ \Omega/m$ or more).

Ratios of E_{peak}/E_0T of the order of 5 seem to be achievable at the energy of 7 MeV. This will improve with higher β. Our spoke model especially needs further improvement to achieve more reasonable ratios of H_{peak}/E_0T. These are predominantly determined by the geometry of the spoke base, where it meets the outer cavity wall.

References

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[3] Frank L. Krawczyk, Nathan K. Bultman, K.C. Dominic Chan, Rick L. Martineau, Subrata Nath, Lloyd M. Young “Design of RF-Cavities in the Funnel of Accelerators for Transmutation Technologies”, Proc. of the ADTT Conference, Las Vegas, Nevada, July 1994

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