RF CAVITY DESIGN AUTOMATION FOR THE APT CCDTL AND CCL *

D.W. Christiansen, Paul Greninger, A.W. Magerski, H.J. Rodarte, P. Smith, G. Spalek,
General Atomics, San Diego, CA

Abstract

As part of the APT project, the Coupled-Cavity Drift Tube LINAC (CCDTL) and Coupled-Cavity LINAC (CCL) designs are being developed.[1] These structures contain 341 cavity segments in 11 different modules. This configuration accelerates a proton beam from 6.7 MeV to 211 MeV. Because of the number of individualized cavity arrangements, an automation design process is being developed. This paper discusses the methods of design automation using Pro-Engineer® as well as programs required to feed the Pro-Engineer® drawing generation process. Such programs include SUPERFISH, where cavity parameters are obtained, as well as programmed analytical methods used to define cavity dimensions that produce the desired level of coupling and $\pi/2$ mode frequency. To compute the coupling, a method developed by J. Gao [2] has been used

1 INTRODUCTION

The Los Alamos Nation Laboratory has had good success predicting coupling in the CCDTL using the J. Gao[2] method. Using that as a bases and extending to automate the CCL and later the CCDTL design, significant progress with design automation has been achieved. Automated design methods are being applied to the first half-size CCL cold model. To date, automated CCL coupling slot geometry calculation methods have been verified, CCDTL calculations will start in FY99. The specific computer code developed for automated design is CCT - Coupled-Cavity Tuning code.

2 MECHANICAL DESIGN AUTOMATION

To guarantee success with the APT Low Energy LINAC design, two design approaches have been incorporated into the design process. The first approach is the full automation of the design process by the use of digital computer codes. The other approach, a more traditional approach, uses linear extrapolation from cold model data. The process flow diagram for the design program is shown in Figure 1. In Figure 1, code development is performed and validated by the use of cold models and other analyses. If the validation is successful, design by code is performed. If the validation is not successful, schedule and funding are not lost. Since code validation requires the use of cold models, the same cold models would be required for use in the non-fully automated process. Additionally, parts of the automation code that can be validated would still be used. This process, therefore, achieves an effective cost and schedule implementation of the design process.

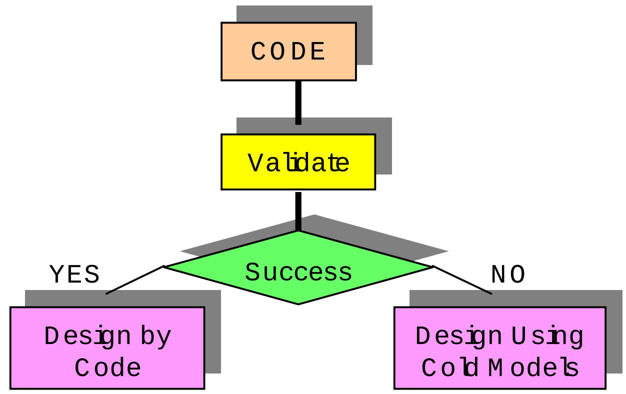

Figure 1. Low Energy LINAC design process flow chart encompassing full automation and use of cold models.

2.1 Coupling Slot Length, Width and Depth

In order to automate design, an analytic formula for calculating coupling cavity to accelerating cavity slot size is needed. Such a formula has been developed. The equations allow for mechanical manipulation of the coupling cavity relative to the on-axis cavity for digital processing. Solved coupling cavity characteristics are cavity size, coupling-slot size, determination of the coupling coefficients and cavity frequency shifts due to the coupling slots. Once determined, the above parameters are used to iterate coupling and cavity parameters to allow for optimization of the design based on desired coupling and $\pi/2$ mode frequency. An example of a slot formed by the overlap (insertion depth) of the CCL coupling cavity and accelerating cavity is shown in Figure 2. Equations for calculating as a function of insertion depth are shown below.

2.1.1 Coupling Slot Length

From Figure 2, sample equations developed for calculating slot length are shown below. In these equations, slot length is determined by the interaction of two circles (one centered on the coupling cavity centerline and the other centered on the accelerating cavity

* - Work supported by the US DOE under the APT Program.

centerline). The radii of these circles are determined at the insertion height where the coupling cavity and accelerating cavities have zero insertion height, refer to Figure 2

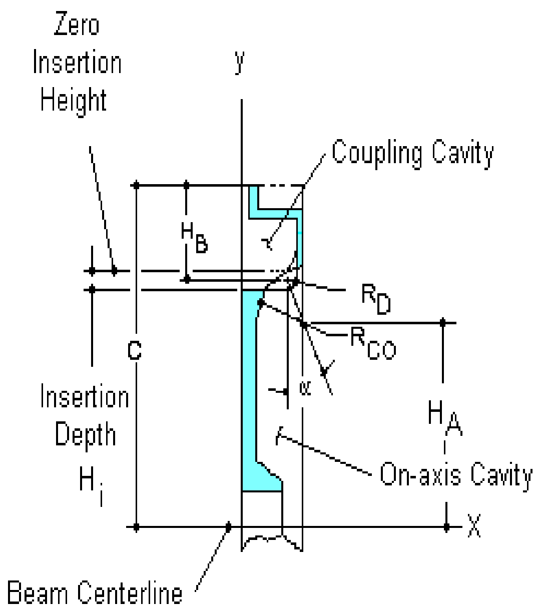

Figure 2. Accelerating cavity to coupling cavity geometry.

$$R_E = H_B + R_D \mathrm{Cos}(\alpha) \qquad (1)$$

$$R_F = H_A + R_{CO} \mathrm{Cos}(\alpha) \qquad (2)$$

$$C_e = R_F + R_E \qquad (3)$$

$$y_i = \frac{-(R_E^2 - R_F^2)}{2(C - H_i)} + \frac{(C - H_i)}{2} \qquad (4)$$

$$x_i = 2[(R_F^2 - y_i^2)]^{0.5}] + 2C_H \qquad (5)$$

$$C_{a_1} = C_e - H_i \qquad (6)$$

Typical slot lengths are shown in Table 1.

Item	H_I (mm)	y_I (mm)	x_I (mm)	C_{ai} (mm)
1	5.08	155.854	55.728	259.893
2	10.16	153.848	76.276	254.813
3	15.24	151.841	91.796	249.733
4	20.32	149.860	104.623	244.653
5	25.40	147.904	115.697	239.573

Table 1. Coupling slot length versus coupling cavity insertion depth.

In Table 1, Item is the case number, H_i is the coupling cavity to accelerating cavity insertion depth, y_i is the height of the slot centerline relative to the beam centerline and C_{ai} is the center to center distance between the coupling cavity and accelerating cavity. C_H in the equations, represents a chamfer around the periphery of the slot, shown in Figure 4.. Results in Table 1 are shown in Figure 3.

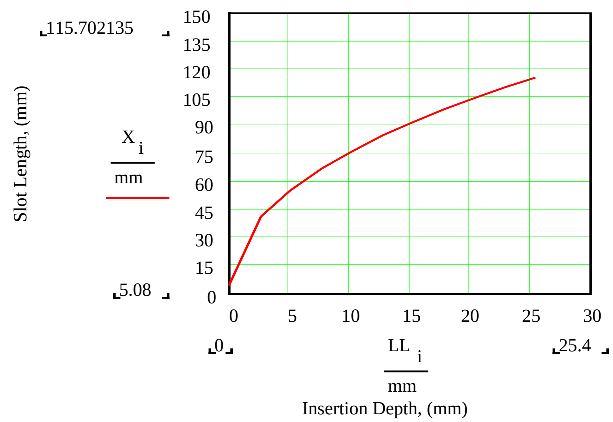

Figure 3. Slot length versus cavity insertion depth.

2.1.2 *Coupling Slot Width and Depth*

Coupling slot width is derived from Figure 4.

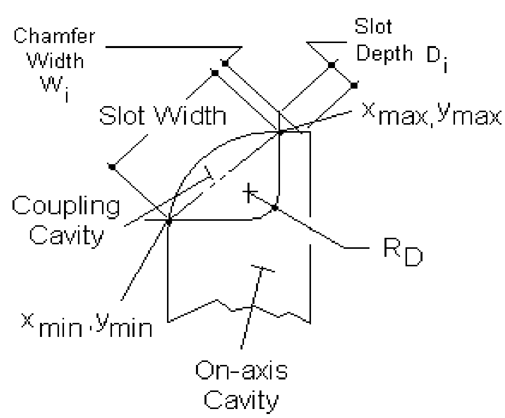

Figure 4. View looking at the center of a typical CCL cloupling slot cross section showing slot width.

In the above, coupling slot width is geometrically defined as the diagonal of two intersecting cavities at the center of the slot in cross section. In equation form, this statement is represented by

$$X_{max_i} = \frac{[-l_i + (l_i^2 - 4m_i n_i)^{0.5}]}{2m_i} \qquad (7)$$

$$X_{min\,i} = \frac{[-l_i - (l_i^2 - 4m_i n_i)^{0.5}]}{2m_i} \qquad (8)$$

$$Y_{max_i} = [R_D^2 - (X_{max_i} - a)^2]^{0.5} + b_i \quad (9)$$

$$Y_{min_i} = [T_D^2 - (X_{min_i} - a)^2]^{0.5} + b_i \quad (10)$$

$$W_i = [(X_{max_i} - X_{min_i})^2 + (Y_{max_i} - \ldots \quad (11)$$

$$\ldots - Y_{min_i})^2]^{0.5} + 2C_H$$

Slot depth is

$$D_i = (Y_{CC_i} - Y_{OC_i})\mathrm{Cos}(\Theta_i) \quad (12)$$

where

$$\Theta_i = \mathrm{Tan}^{-1}\left[\frac{(Y_{max_i} - Y_{min_i})}{(X_{max_i} - X_{min_i})}\right] \quad (13)$$

In the solution of these equations, l_i is the second Bernoulli term, m is the first Bernoulli term and n is the third Bernoulli term of a solved set of second order equations. R_D is the coupling cavity radius and b equals $C-H_B-H_I$ from Figure 4. YCC and YOC are vertical distances from the horizontal beam axis to the coupling cavity and on-axis cavity intersection at the extreme end of the slot. A sample of slot size versus insertion depth is shown in Figure 5.

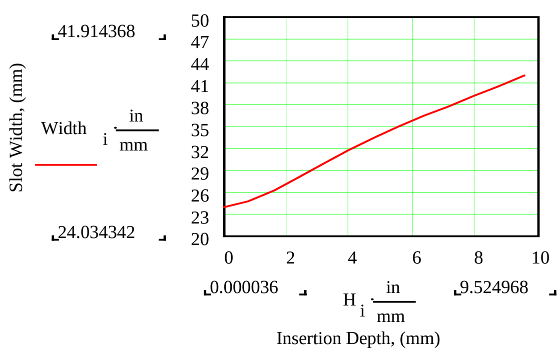

Figure 5. Prototypic CCL coupling slot width.

Determination of cavity geometries with the above equations follows the following general flow of information: SUPERFISH is used to generate initial cavity data. CCT then reads the SUPERFISH input and output files and calculates the slot configuration. If either the final cavity frequency and/or coupling coefficient are off, the cavity geometry is adjusted and the process is repeated. This process continues until cavity frequency and coupling are achieved. Output results are then calculated for ambient 68 °F conditions and fed to automated Pro-Engineer® drafting programs for cavity design.

3 PHYSICS AUTOMATION

There are two areas that deserve mention for the physics automation process. These areas are frequency shift due to coupling and coupling coefficient [1]. To automate the mechanical accelerator design process, the mechanical computer code integrates the physics design calculations. For the frequency shift due to the coupling slots, the frequency shift is

$$\Delta f = k_1 f_0 \frac{[\mu_0 \pi (\frac{x_i}{2})^3 e_0^2 H_1^2]}{[k_2 (K(e_0)_i - E(e_0)_i) U_1]} \quad (14)$$

Where:
- Δf = Change in frequency due to coupling slots
- f_0 = Unperturbed frequency of the cavity
- μ_0 = Permeability of free space
- x_i = Length of the coupling slot
- e_0 = $[1-(x_i/W_i)^2]^{1/2}$
- H_1 = Unperturbed field in on-axis cavity
- $K(e_0)$,$E(e_0)$ = Complete elliptic integral of the first and second kind
- U_1 = Unperturbed stored energy in on-axis cavity
- k1 = Constant determined from cold model testing
- k2 = 12 for cavities with two coupling slots and 6 for one coupling slot

For Coupling

$$k = \frac{\pi \mu_0 e_0^2 (\frac{x_i}{2})^3 H_1 H_c}{3[K(e_0)_i - E(e_0)_i]\sqrt{U_1 U_c}}\}e^{-\varsigma D_i} \quad (15)$$

(16)

and
- H_c = Unperturbed field in the coupling cavity
- U_c = Unperturbed stored energy in the coupling cavity
- ς = Attenuation coefficient of the slot considered as a waveguide.

4 REFERENCES

[1] Thomas Wangler, RF Linear Accelerators, Copyright 1998, John Wiley & Sons, Inc.

[2] J. Gao, "Analytical Formulas for the Resonant Frequency Changes Due to Opening Apertures on Cavity Walls," Nucl. Instr. And Meth in Physics Research. A311 (1992)p. 437-443.