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

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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.

\[ R_E = R_H + R_D \cos(\alpha) \]  
\[ R_F = H_A + R_{CO} \cos(\alpha) \]  
\[ C_c = R_F + R_E \]  
\[ y_i = -\frac{(R_{E_i}^2 - R_{F_i}^2)}{2(C - H_i)} + \frac{(C - H_i)}{2} \]  
\[ x_i = 2\left(\left(R_{E_i}^2 - y_i^2\right)^{0.5}\right) + 2C_{ai} \]  
\[ C_{ai} = C_c - H_i \]

Typical slot lengths are shown in Table 1.

<table>
<thead>
<tr>
<th>Item</th>
<th>(H_i) (mm)</th>
<th>(y_i) (mm)</th>
<th>(x_i) (mm)</th>
<th>(C_{ai}) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.08</td>
<td>155.854</td>
<td>55.728</td>
<td>259.893</td>
</tr>
<tr>
<td>2</td>
<td>10.16</td>
<td>153.848</td>
<td>76.276</td>
<td>254.813</td>
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<tr>
<td>3</td>
<td>15.24</td>
<td>151.841</td>
<td>91.796</td>
<td>249.733</td>
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<tr>
<td>4</td>
<td>20.32</td>
<td>149.860</td>
<td>104.623</td>
<td>244.653</td>
</tr>
<tr>
<td>5</td>
<td>25.40</td>
<td>147.904</td>
<td>115.697</td>
<td>239.573</td>
</tr>
</tbody>
</table>

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. \(C_{ai}\) 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.

\[ X_{max,i} = \frac{-I_i + (I_i^2 - 4m_i n_i)^{0.5}}{2m_i} \]
\[ X_{min,i} = \frac{-I_i - (I_i^2 - 4m_i n_i)^{0.5}}{2m_i} \]
\[ Y_{\text{max}} = [R_D^2 - (X_{\text{max}} - a)^2]^{0.5} + b \]  
\[ Y_{\text{min}} = [T_D^2 - (X_{\text{min}} - a)^2]^{0.5} + b \]  
\[ W_i = [(X_{\text{max}} - X_{\text{min}})^2 + (Y_{\text{max}} - Y_{\text{min}})^2]^{0.5} + 2C_H \]

Slot depth is

\[ D_i = (Y_{\text{CCi}} - Y_{\text{OCi}}) \cos(\Theta_i) \]

where

\[ \Theta_i = \tan^{-1}\left(\frac{Y_{\text{max}} - Y_{\text{min}}}{X_{\text{max}} - X_{\text{min}}}\right) \]

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. \( R_x \) is the coupling cavity radius and \( b \) equals \( C-H \) from Figure 4. \( Y_{\text{CC}} \) and \( Y_{\text{OC}} \) 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.

![Graph showing slot width versus insertion depth](image-url)

Figure 5. Prototypic CCL coupling slot width.

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

\[ \Delta f = k_1 f_0 \left[ \frac{\mu_0 x_0^2}{2} \right] \]

\[ \left[ \frac{K(e_0)}{e_0} \right] \]

Where:

- \( \Delta f \) = Change in frequency due to coupling slots
- \( f_0 \) = Unperturbed frequency of the cavity
- \( \mu_0 \) = Permeability of free space
- \( x_i \) = Length of the coupling slot
- \( e_0 \) = \( 1 - (x_i/W_i)^2 \)
- \( H_i \) = Unperturbed field in on-axis cavity
- \( K(e_0), E(e_0) \) = Complete elliptic integral of the first and second kind
- \( U_i \) = Unperturbed stored energy in on-axis cavity
- \( k_1 \) = Constant determined from cold model testing
- \( k_2 \) = 12 for cavities with two coupling slots and 6 for one coupling slot

For Coupling

\[ k = \frac{\pi \mu_0 e_0^2 (x_i)}{2} \]

\[ 3(k - K(e_0)) \frac{U_i}{U_i} e^{-\zeta} \]

\[ \zeta = \text{Attenuation coefficient of the slot considered as a waveguide.} \]

4 REFERENCES