Frequency Domain Determination of the Waveguide Loaded Q for the SSCL Drift Tube Linac*

J. Petillo, W. Krueger, A. Mondelli
Science Applications International Corporation
1710 Goodridge Drive, McLean, VA 22102

J. Potter
AccSys Technology, Incorporated
1177 Quarry Lane, Pleasanton, CA 94566

I. INTRODUCTION

An important problem in the design of RF linacs is the coupling between the waveguide that feeds RF power into the accelerator and the cavity through which the beam is being accelerated. The designer needs to know the coupling coefficient, the frequency shift, and the external Q due to the waveguide. In addition, the details of the field geometry in the vicinity of the aperture are important in the design.

In this paper, the simulation code ARGUS has been employed in a collaboration between SAIC and AccSys Technology, Inc. to model the external Q of the drift tube linac (DTL) tanks in the injector of the Superconducting Super-Collider (SSC). (The drift tube linear accelerators are designed and built by AccSys Technology.) As the coupling aperture (iris) size and shape is changed, the coupling factor changes. This paper presents results of numerical simulations produced to aid in determining the optimum iris size for power coupling to the tank. A comparison of the simulation results will be made with results from experimental data.

II. DTL MODEL

The intrinsic Q of the DTL cavity is about 40,000. Figure 1 presents a cross section of the device, showing the waveguide feed, the coupling iris, and the cavity. Dimensions of the structure are the following: tank radius, $R_i = 21$ cm; tank wall thickness, $T_w = 1$ cm; waveguide height and width, $H_w = 9$ in by $W_w = 18$ in. It was desired to study iris widths of $W_i = 12$, 15, or 18 cm, with iris lengths ranging from $W_i < L_i < 30$ cm. Due to time constraints, only the $W_i = 12$ cm set of irises were fully modeled. It should be noted that the coupling iris is oval, in general, when projected onto a plane transverse to the waveguide axis. The smallest iris for any of the widths listed above is represented by a circle in the projected plane.

The requirements for the model were that the tank diameter be the same as the DTL so that the coupling iris would have the actual curvature, and that the frequency

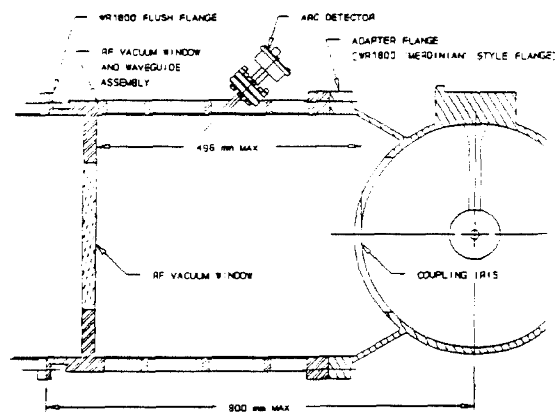

Figure 1: Waveguide to DTL tank coupling geometry.

be the same as the DTL. It was chosen to load the cavity with a dielectric rod along the axis to achieve the desired frequency. The dielectric has a radius of 4 cm and a relative dielectric constant of $\epsilon_R = 4.98$. This results in a cavity frequency of $f_c = 427.717$ MHz. Scaling the SUPERFISH data for the dielectric loaded cylinder to the same wall current as the DTL yields a required cylinder length of 10.525 m for the model to have the same stored energy as the DTL operating at the design field.

Due to the expected high Q of the device (17,500-70,000) and the high detail of the structure in the vicinity of the coupling iris (requiring high resolution gridding), time domain calculations are too costly. However, there are several methods available for determining the external Q of a waveguide loaded cavity device using a resonant frequency and eigenmode solver. We used two of these methods; one by Goren and Yu[1], and another by Kroll and Yu[2]. Although both methods provide good results, each has its inherent advantages and disadvantages for our particular use. The ARGUS code provided the frequency domain solver.

In our study, although both of the methods are used and compared, only the Goren and Yu (GY) method is used for all the iris sizes studied. A comparison of the simulation results will be made with results from experimental data.

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III. METHODS

The two methods, the Kroll-Yu (KY) method and the Goren-Yu (GY) method, are similar in that they both employ a frequency domain solver to find the modes of a shorted waveguide loaded cavity. In particular, for each iris shape, several runs are made where the distance to the waveguide short is varied from run to run. However, the two methods differ by using the resulting simulation data in completely different ways to arrive at the external Q.

In the Kroll-Yu (KY) method, four runs are required for a good result[2] in our case. In this method, a resonance curve of phase shift along the waveguide vs. mode frequency shift is mapped out as shown in the example of Fig. 2. The simulation data (denoted by the four solid black circles in the plot) is fitted to a resonance curve. The slope of that curve multiplied by one-half the resonant frequency (apart from a small correction[2]) results in the Q_{ext}. An important point for the KY method is to

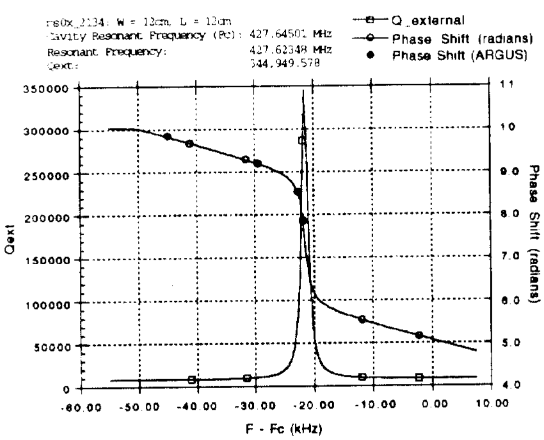

Figure 2: Phase shift vs. frequency example for a 12 cm by 12 cm iris aperture with a truncated DTL tank length.

choose lengths for the waveguide that sufficiently sample the slope inside the resonance curve, since the Q results from the maximum derivative of the curve. The difficulty here is that some of the shorting planes must be placed in extremely close proximity to the actual null in the transverse fields along the waveguide for this to occur. It may take several runs to find the proximity of this null. It should be noted that, by chance, if the short could be placed exactly at the null, then the actual solution to the problem would be known.

Another difficulty in using the KY method is that sampling several points inside this resonance requires judicious choices for gridding techniques as the shorted waveguide length is changed from run to run. The changes in frequency from run to run occur in the sixth and seventh decimal point, requiring about eight significant digits for sufficient accuracy. It should be noted that, although the numerical procedure cannot get the continuous-space answer to the frequency to eight significant digits, it can get the result on the numerical grid to that accuracy. This point is crucial to the use of both of the methods used in this paper. It means that the changes to the grid from one waveguide length to another have to be done carefully. Basically, the grid along the axis of the waveguide has to be uniform in the vicinity of the short, and the lengths modeled have to be such that they lay on multiples of that uniform cell size. This seemed to allow the solver to behave sufficiently to give the necessary eight significant digits for the mode of interest. Given this restriction, in addition to the loaded Q, the KY method provides an accurate resonance frequency so that frequency shifts are attained.

In the Goren-Yu (GY) method, only two runs are required. This method is based on determining the power flow through the waveguide from an analysis of the details of the standing-wave fields inside the waveguide. Each run provides a relationship between the outgoing electric field versus the reflection coefficient due to the coupling iris. Thus, two runs can be sufficient to solve the problem. With the resultant outgoing power, a shunt resistance can be calculated, giving a waveguide loaded Q.

This method works extremely well, and does not require locating the short circuit so close to the actual zero in the transverse fields along the waveguide. However, this method still requires the same cautious gridding in the vicinity of the short circuits. In addition, for sufficient accuracy, the method demands a particularly accurate location of the peak in the field along the waveguide axis, as well as the field's null position.

IV. SIMULATION RESULTS

Although the full range of iris widths and lengths mentioned previously were considered, this paper only presents the case of the iris width of $W_i = 12$ cm with heights of $H_i = 12$, 18, 24, and 30 cm. Figure 3 shows views of the waveguide/iris/cavity geometry as represented by the ARGUS code.

Since the two methods can use data from the same frequency domain calculation, (although each uses the data differently) a direct comparison between the two methods could be done. This comparison was made on the 12 cm by 12 cm iris only. On the basis of predicting a waveguide loaded Q, the comparison yielded extraordinarily good agreement. The two methods predicted values for the Q within 1% of one another. (Please note that the results shown in Fig. 2 are for a truncated DTL tank and does not represent the nontruncated results presented below.)

Only the GY method was used on the full family of four iris shapes. Figure 4 shows the results of these four runs for the 12 cm wide iris. The solid black dots represent the results from the GY method. For the KY method, only one value for Q was attained (corresponding to the leftmost one on the plot), along with the frequency shift noted by the solid black square on the plot. For the GY method,

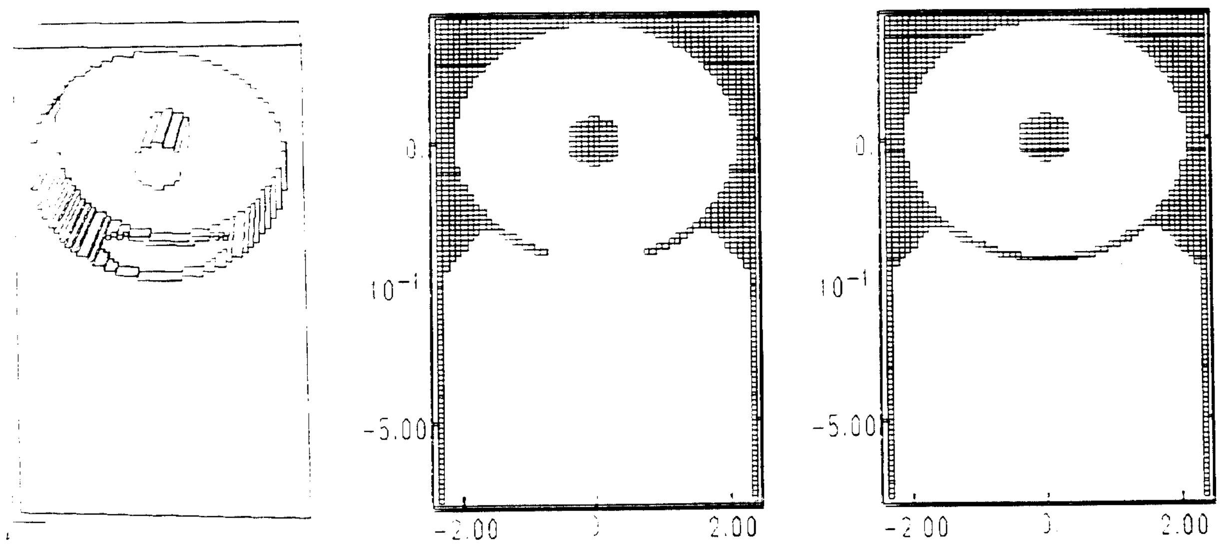

Figure 3: Waveguide to DTL tank coupling iris geometry as represented by ARGUS.

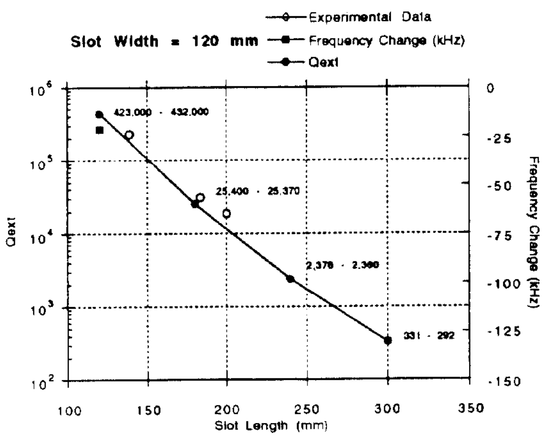

Figure 4: External Q and frequency shift vs. iris length for the 12 cm wide iris aperture.

several values of Q were determined for each case, since more than two runs were made for each case. This was done to determine the robustness of the method. On the plot, the numbers adjacent to the solid black dots represent the range of values of Q from the GY method. For the leftmost value, the KY method gave a result within 1% of the values in the band. As can be seen from the plot, these ranges of values were within a 2% range for the leftmost three points, where the rightmost point's range spanned slightly more than 10%. On the plot in Fig. 4, the experimental results (shown by the hollow circles) show excellent agreement with the numerically predicted values.

V. CONCLUSION

The need to determine the waveguide loaded Q for various iris shapes by numerical procedures is very important for many reasons. It is ultimately desired to produce a highly efficient system by exploring many different designs. An experimental determination in our case by trying many iris sizes and shapes is somewhat unfeasable; however, using computer simulations to study a myriad of irises is more realistic. In our collaboration, we were able to verify results of experimental measurements combined with theoretical methods with the simulation model's results.

With respect to the two frequency domain methods used, the Kroll-Yu method and the Goren-Yu method, it was shown that the two methods give excellent agreement with one another. The KY method has the disadvantage that it required shorting the waveguide in close proximity of the true null for best results. Also, it required four runs for a result; however, that result gave, in addition to the Q, a resonant frequency indicating the frequency shift. The GY method, on the other hand, although not directly giving the resonant frequency of the resultant structure, only required two runs for a result for the Q, and did not necessarily dictate choosing the shorting planes so close to the true null. In all cases, the agreement between the simulation models and experimental results was quite good.

VI. REFERENCES

[1] Y. Goren and D. U. L. Yu, "Computer Aided Design of Three-Dimensional Waveguide Loaded Cavities," SLAC/AP-73, Feb. 1989.

[2] N. M. Kroll and D. U. L. Yu, "Computer Determination of the External Q and Resonant Frequency of Waveguide Loaded Cavities," *Particle Accelerators*, 34(231), 1990.