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

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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, \( R_i = 21 \text{ cm} \); tank wall thickness, \( T_w = 1 \text{ cm} \); waveguide height and width, \( H_w = 9 \text{ in} \) by \( W_w = 18 \text{ in} \). It was desired to study iris widths of \( W_i = 12, 15, \) or \( 18 \text{ cm} \), with iris lengths ranging from \( W_i < L_i < 30 \text{ cm} \). Due to time constraints, only the \( W_i = 12 \text{ cm} \) 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. 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 \( 4 \text{ cm} \) and a relative dielectric constant of \( \varepsilon_r = 4.98 \). This results in a cavity frequency of \( f_c = 427.717 \text{ MHz} \). Scaling the SUPERFISH data for the dielectric loaded cylinder to the same wall current as the DTL yields a required cylinder length of \( 10.525 \text{ m} \) 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.
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 resonance frequency so that frequency shifts are attained.

The KY 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,
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 unfeasible; 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
