TUNING OF THE WAVEGUIDE TO CAVITY COUPLING COEFFICIENT FOR A PWT LINAC AND A PHOTOCATHODE GUN

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Abstract

The waveguide to cavity coupling coefficient β for two types of accelerating structures: a Plane Wave Transformer (PWT) linac and a 1.6 cell photocathode gun have been tuned to obtain critical coupling in both. Analytical calculations of the dimensions of the slot required for critical coupling have been done using Gao's formulation based on the Bethe's theory for hole coupling. While the PWT linac structure, with high inter-cell coupling, shows good agreement between measured and predicted slot dimensions for different values of β, the agreement is not so good in the photocathode gun on account of poor inter-cell coupling and a new tuning method has been devised to tune the gun. This paper discusses details of the analytical calculation of slot dimensions for the two structures, their comparison with experimentally measured results, and the procedure adopted for tuning the two structures to critical coupling.

INTRODUCTION

The RF coupling coefficient (β) of a waveguide to cavity system gives a measure of the power coupled to the cavity, and is defined as the ratio of power loss in the matched load of the wave guide to the power dissipated inside the cavity [1]. Its value depends critically on the dimensions of the coupling slot, and it is usually tuned experimentally to the desired value by iteratively changing the length of slot and measuring the actual value of β.

Gao has developed a scaling law to fix dimensions of the coupling slot for any desired value of β [2] in a system with a single cavity coupled to a waveguide through a slot. Since we wanted to tune β for two multi-cell structures, a four-cell PWT linac structure and a 1.6 cell BNL/SLAC/UCLA type RF photocathode gun structure, we proposed to extend Gao's analysis by incorporating the effect of inter-cell coupling to be able to correctly predict the required slot dimensions. Before doing this, we employed Gao's scaling law for the PWT linac and photocathode gun to study the extent of disagreement and possible reasons for it. While the agreement is poor in the gun, the PWT linac shows good agreement between measured and predicted values of β on account of good inter-cell coupling. It may be noted here that in addition to tuning the gun to β = 1, it is required to simultaneously obtain field balance FB =1 and frequency of the π mode f_π = 2856 MHz.

In the next section, we discuss the procedure employed to tune the β for the two accelerating structures. Results obtained in tuning the PWT linac structure and the photocathode gun is discussed in sections 3 and 4 respectively. We conclude with a discussion of the results in section 5.

WAVEGUIDE TO CAVITY COUPLING COEFFICIENT β

Figure 1 shows the equivalent circuit of a simple cavity - waveguide coupled system where RF power in the waveguide is coupled to the cavity through a slot machined on its wall. Gao's scaling formula for the β of such a system, considering an elliptical slot, is given by

$$\beta = \frac{16 Z_0 \kappa_0 \Gamma_{10} l_1^6 \exp(-2\alpha_0 d)}{9ab\left(1+\frac{3}{8}e_0^2+\frac{15}{64}e_0^4+\frac{315}{3072}e_0^6+\ldots\right)^2}\frac{H_1^2}{P_c}, \quad (1)$$

where H_1 is the magnetic field strength on the wall of cavity when there is no coupling slot, l_1 is the major axis of the coupling slot, and all other symbols have the same meaning as given in reference [2].

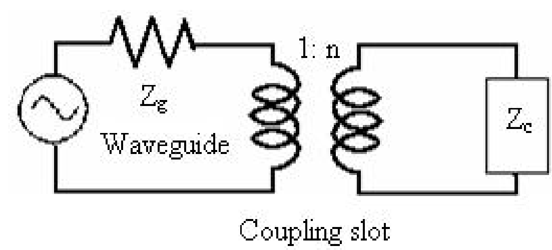

Figure 1: The equivalent circuit of a waveguide to cavity coupled system.

The value of H_1^2/P_c can be determined either from simulations using electromagnetic field solver codes or by measuring the value of β for a very small slot size and extracting the value of H_1^2/P_c from it using Gao's formula. Since simulations consider ideal conditions, which may be different from actual experimental conditions, we followed the latter method. The dimension of the slot machined initially was very small giving β ~0.05. Assuming this to be like a structure without any slot, Eq. 1 was used with the measured β to obtain a value of H_1^2/P_c, which was subsequently employed again in Eq. 1 to predict values of β for different slot sizes.

TUNING β OF A PWT LINAC

Figure 2 shows a schematic of a 4-cell PWT linac built by us. On account of its coaxial geometry, RF in the waveguide couples to the plane waves supported by the coaxial geometry of the structure. These waves, which set up a standing wave pattern after repeated reflections from the two end walls of the structure, couple power between the cells. Boundary conditions close to the axis result in the generation of the desired TM_{010} like field pattern in this region.

Though this is a 4-cell structure (3 full + 2 half), the waveguide transfers power into the coaxial region of the structure through the coupling slot, instead of coupling to any one cell of the structure as in conventional linac structure. Hence, the measured and predicted values of β for any given slot size show good agreement with those predicted by Gao's analysis.

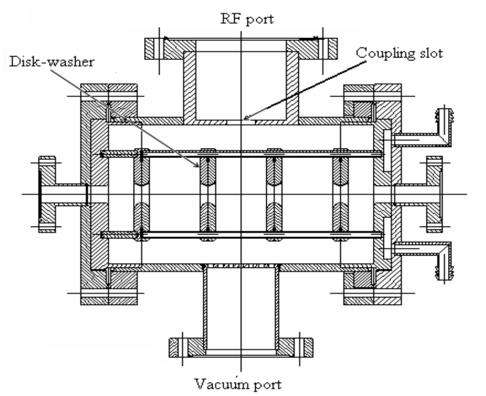

Figure 2: Schematic of a 4-cell PWT linac.

We have successfully built and tuned the β of four 4-cell PWT linac structures employing Gao's scaling law. The first two PWT structures are cold test prototypes while the third structure has been successfully employed to accelerate a 40 keV beam from a thermionic electron gun to 3.5 MeV [3]. The fourth structure is currently being conditioned.

Table 1:Comparision of β for Different PWT Linacs

Prototype	Slot size	β (Predicted)	β (Measured)
PWT1	33.2	1.02	1.022
PWT2	38.6	0.97	0.99
PWT3	38	0.9	1.02

Initially, the dimensions of the machined slot are chosen to be very small resulting in a measured $\beta \sim 0.05$. Assuming this to be like an unperturbed structure without slot, this measured value of β is used in Eq. 1 to obtain the value of H_1^2/P_c for the structure. Using this value, dimensions of the slot are predicted to ultimately reach critical coupling. For the first two cold-test prototypes, dimensions of the slot were increased in steps to study the agreement between measured and predicted values of β at each step. With the confidence obtained from tuning these two prototypes, the final two structures were tuned to critical coupling in a maximum of 3 steps. Table 1 shows a comparison of the measured and predicted values of β for the different structures. It may be noted here that since all structures have different RF properties, particularly the first two prototypes, the dimensions of the coupling slot for critical coupling are different. Figure 3 shows the agreement between predicted and measured values of β for different slot sizes on the second prototype PWT structure.

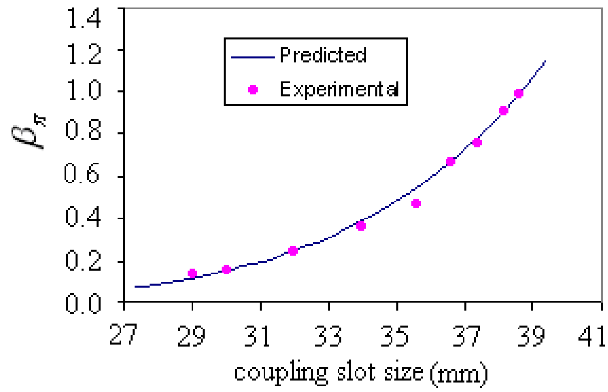

Figure 3: Waveguide to cavity coupling coefficient β verses coupling slot length.

TUNING β OF A PHOTOCATHODE GUN

A schematic of a 1.6 cell BNL/SLAC/UCLA type S-band photocathode gun is show in fig 4. Here, power is coupled from a waveguide to the TM_{010} mode supported by the full cell and part of this power is then coupled to the half-cell through the coupling iris between the full and half cells. From operational considerations, a photocathode gun needs to be tuned to a π mode frequency f_π of 2856 MHz and a field balance FB, which is the ratio of the field in the full cell to that in the half cell, of unity simultaneously with tuning β to critical coupling.

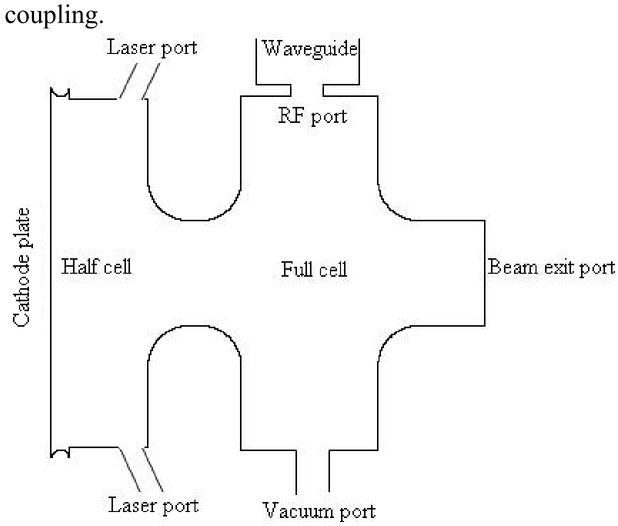

Figure 4: Cross section of 1.6 cell photocathode gun.

Initially, we ignored the requirement of tuning the FB and f_π to study the variation of β with slot dimensions as predicted by Gao's scaling laws. Since the full-cell of the gun is coupled to the half-cell through an iris, the measured value of β actually shows the coupling coefficient between the waveguide and the coupled two-cavity system. Gao's scaling law is applicable only to a single cavity coupled to a waveguide and the agreement between measured and predicted values of β for the gun is therefore very poor.

The coupling between the two cells of the gun can be eliminated if their frequencies are taken far apart such that there is no overlap between their Q curves. For a gun, this can be done by employing a plunger to detune the half cell. In such a situation, the measured value of β is just the independent full cell to cavity coupling coefficient

Tuning of a multi-cell structure like a photocathode gun requires a different method, which includes the contribution of inter-cell coupling in the calculation of β. Since there is a strong inter-dependence between β, f_π, and FB, tuning a photocathode gun is more involved and is usually accomplished iteratively employing a cut-and-measure technique. We have extended Gao's analysis to include the coupling between two cavities to devise a two-step tuning procedure [4], which has been employed to successfully tune two prototypes of a 1.6 cell photocathode gun. A comparison of results obtained experimentally with those predicted by our analysis is given in Table 2. Figure 5 shows Smith Chart of tuned ETPGUN.

Table 2: A Comparison of Experimental Measurements with Predictions.

Parameters	AGUN		ETPGUN	
	Predicted	Measured	Predicted	Measured
f_π (MHz)	2856	2856.28	2856	2856.294
e_b	1.00	1.04	1.00	1.06
β_π	1.00	1.06	1.00	1.02
β_f	1.69	1.67	1.72	1.69

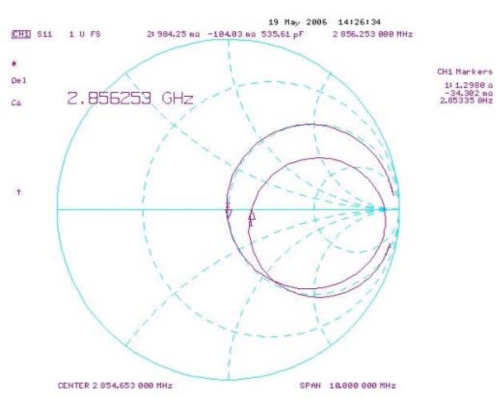

Figure 5: Smith Chart of the tuned ETPGUN.

CONCLUSION

We have successfully applied Gao's scaling law to tune the β of four PWT linac structures. For the gun, Gao's analysis has been extended to include the contribution of inter-cell coupling and a new two-step method has been developed to simultaneously tune f_π=2856 MHz, FB = 1 and β=1.

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