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RF NOTE #105

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MEASUREMENT RESULTS FROM LOW POWER MODEL WITH RACETRACK DEE

Contents

A. Theory

The K800 dee design was varied recently because the original design could not supply the desired extraction voltage. To fulfill the extraction voltage requirement, the stem was moved 8" closer to the dee tail. The dee shape was also changed in parts to give it more of a "flattop" look.

The model which was used during these tests was a scale model (1:1) of the actual dee design. The stem length for the sliding short was set for 0.5".

The measurements taken for these tests were used to empirically derive the extraction voltages.

The measurements which were taken for the low power model test are used to find the βd variations in voltage about the dee periphery[1]. In general, we can model a given cavity using only its equivalent series values for its resistive, inductive, and capacitive components. Let the resonant frequency $f_0 = 2\pi\omega_0$ where f_0 is in Hertz and ω_0 is the resonant frequency in radians/sec. Thus,

$$\omega_0 = \frac{1}{\sqrt{LC}} \qquad \text{where } L = \text{equivalent inductance},\ C = \text{equivalent capacitance}$$

If we want to determine the incremental change in either capacitance or inductance as we step around the dee, we use:

$$f_0 = \frac{(LC)^{-\frac{1}{2}}}{2\pi}$$

$$\frac{df_0}{dC} = \frac{1}{2\pi}\left(-\tfrac{1}{2}\right)(LC)^{-\frac{3}{2}}(L)$$

$$= -\left(\frac{1}{4\pi} L^{-\frac{1}{2}}C^{-\frac{3}{2}}\right)$$

$$\frac{df_0}{dC} = -\frac{1}{4\pi L^{\frac{1}{2}}C^{\frac{3}{2}}}$$

Also,

$$f_0 = \frac{(LC)^{-\frac{1}{2}}}{2\pi}$$

$$= \frac{1}{2\pi(LC)^{\frac{1}{2}}}$$

$$f_0 = \frac{1}{2\pi L^{\frac{1}{2}}C^{\frac{1}{2}}}$$

$$L^{\frac{1}{2}} = \frac{1}{2\pi f_0 C^{\frac{1}{2}}}$$

Let $\frac{df_0}{dC} \approx \frac{\Delta f_0}{\Delta C}$

[1] Vincent, John, "Low Power Model Measurements," April 23, 1985, unpublished.

$$\frac{\Delta f_0}{\Delta C} = -\frac{1}{4\pi\left(\frac{1}{2\pi f_0 C^{\frac{1}{2}}}\right)C^{\frac{3}{2}}}$$

$$= -\frac{f_0}{2C}$$

Thus,

$$\frac{\Delta f_0}{\Delta C} = -\frac{f_0}{2C}$$

$$C = -\frac{f_0}{2\frac{\Delta f_0}{\Delta C}}$$

f_0 is measured
Δf_0 is calculated
ΔC is known

The Boonton probe, and the capacitor we used for the capacitor test, have very small capacitances. So, the change in total capacitance is very small and can be neglected. Thus, the change in voltage distribution can be neglected.

Let the stored energy equal

$$U_n = \tfrac{1}{2}C_n V_n^2$$

for a particular step (point) along the periphery.

Let

$$U_{n+1} = \tfrac{1}{2}C_{n+1} V_{n+1}^2$$

for the next point along the periphery.

Since

$$\frac{U_n}{U_{n+1}} \approx 1,$$

then

$$\frac{\tfrac{1}{2}C_n V_n^2}{\tfrac{1}{2}C_{n+1} V_{n+1}^2} \approx 1$$

$$\frac{C_n}{C_{n+1}} = \frac{V_{n+1}^2}{V_n^2}$$

$$\frac{V_{n+1}}{V_n} = \left(\frac{C_n}{C_{n+1}}\right)^{\frac{1}{2}}$$

Using

$$C = -\frac{f_0}{2\frac{\Delta f_0}{\Delta C}}$$

$$\frac{V_{n+1}}{V_n} = \left(\frac{-\frac{f_0}{2\frac{\Delta f_{o_n}}{\Delta C}}}{-\frac{f_0}{2\frac{\Delta f_{o_{n+1}}}{\Delta C}}}\right)^{\frac{1}{2}}$$

$$= \left(\frac{\Delta f_{o_n}}{\Delta f_{o_{n+1}}}\right)^{\frac{1}{2}}$$

Thus

$$\left(\frac{V_{n+1}}{V_n}\right)^2 = \left(\frac{\Delta f_{o_n}}{\Delta f_{o_{n+1}}}\right)^{\frac{1}{2}\,2}$$

Thus, we can determine the voltage variation on the periphery of the dee by measuring the change in resonant frequency.

B. Methods of Measurements

There were two methods of measurement. For the first, we stepped a small capacitor around the inner periphery of the dee to perturb the cavity. Then we calculated the square root of the ratio between the perturbed resonant frequency and the compensated (natural) resonant frequency to find the percentage of the maximum in the dee at the measured step.

For the second method, we used two Boonton RF voltmeters to find the percentage of the maximum voltage in the dee at the measured step. First, we measured the voltage using one of the Boontons at the short area and found the natural resonant frequency. Next, we inserted the second Boonton's probe at steps along the dee's inner periphery. The new (perturbed) resonant frequency was then found. The amplitude of the input signal was adjusted to a set level from the Boonton voltage on the short (in our case it was 0.15V) and the Boonton on the dee was read. We then used the equation

$$100 \times \frac{V_{n+1}}{V_n} = \% \text{ of maximum voltage}$$

to determine periphery voltages.

C. Test Data

RACETRACK DEE

Test 1 Using Small Capacitor

f_0 = 28.68325MHz
Short Length = ½"

Point	1A*	1	2	3	4
f_{o_n}		28.42620	28.47677	28.45353	28.42730
Δf_o		0.25705	0.20648	0.22572	0.25595
V_n		100%	89.62%	94.53%	99.78%

* Unable to insert capacitor at this point

Test 2 Using Boontons

f_0 = 28.68325Mhz
Short Length = ½"

Point	1A	1	2	3	4
f_{o_n}	28.51670	28.52480	28.56065	28.54260	28.53960
Δf_o	0.16655	0.15845	0.12260	0.14065	0.14365
Boonton (V_n)	2.36	2.27	2.06	2.08	2.20
V_n	100%	96.18%	87.28%	88.13%	93.22%

Thus, the variation in resonant frequency closely equals (as predicted) the variation in voltage.

Note, since point 1A was inaccessible to the capacitor, to compare the two tests, we must normalize the data.
So,

Point	1	2	3	4
Test 1	96.18%	86.19%	90.91%	95.96%
Test 2	96.18%	87.28%	88.13%	93.22%

Thus, if 100% of V_n = 200KV, then voltage at point 4, for example, is ≈ 190KV. See Figure 1 for test point locations.

C. Test Data (cont.)

ORIGINAL DEE

Test 1 Using Small Capacitor

f_0 = 27.15420MHz
Short Length = 1"

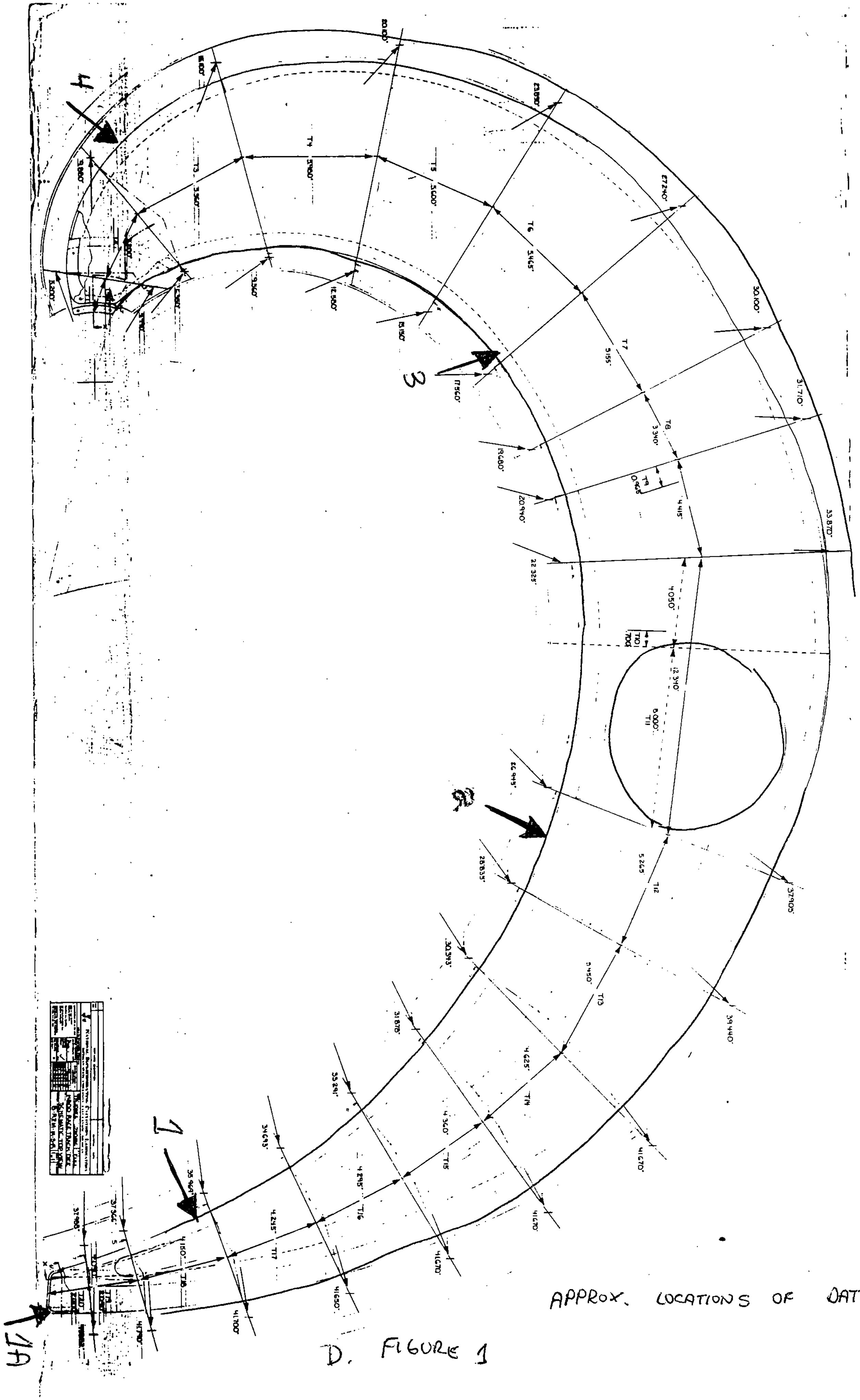
Point	1A*	1	2	3	4
f_{o_n}		26.95273	26.98233	26.93450	26.90483
Δf_o^n		0.20147	0.17187	0.21970	0.24397
V_n		89.88%	83.02%	93.86%	100%

* Unable to insert capacitor at this point.

Test 2 Using Boontons

f_0 = 27.16420
Short Length = 1"

Point	1A	1	2	3	4
Boonton (V_n)		38.5	36	40.2	42.6
V_n		90.38%	84.5%	94.37%	100%



APPROX. LOCATIONS OF DATA POINTS

D. FIGURE 1

E. Conclusion

As can be seen from the test data, the racetrack dee's voltage between points 1 and 2 (the extraction area) increased significantly from the original design's voltage. Also, this increase in extraction voltage was not gained at the expense of a reduced upper resonant frequency.

Thus, the racetrack dee design allows us to have the higher extraction voltages and a good upper resonant frequency without having to perform major renovations of other components of the cyclotron.