This report deals with some preliminary measurements of iris-loaded waveguide structures, when these structures are operated as π-mode standing wave accelerators.

The parameters considered are the shunt impedance per unit length ($R_s$), bandwidth (BW), and tank flatness. This paper discusses some preliminary measurements of the above parameters, in an effort to establish design criteria.

Table I lists the various parameters of the three types of iris-loaded structures considered. All calculations and measurements are for the π mode. The shaped irises are based on the calculations of R. L. Gluckstern. (1) The waveguide with flat irises is of the type usually referred to as a "standard disk-loaded structure." The slotted structure has four radial slots as shown in Fig. 1. An improvement in the shunt impedance was obtained with the addition of nose cones. In all three structures, the center hole was 2 in, and outer wall diameter, 10 in. The operating frequencies of the various structures were between 800 and 900 Mc/sec, but all measurements shown in Table I are scaled to 880 Mc/sec.

The test model was made of unit cells, which were held together with tie rods. The unit cell length was
<table>
<thead>
<tr>
<th></th>
<th>SHAPED IRIS</th>
<th>FLAT IRIS</th>
<th>SLOTTED IRIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta$</td>
<td>.55</td>
<td>.55</td>
<td>.55</td>
</tr>
<tr>
<td>$R_s$</td>
<td>12.3 $\text{M} \Omega/\text{m}$</td>
<td>12 $\text{M} \Omega/\text{m}$</td>
<td>12.3 $\text{M} \Omega/\text{m}$</td>
</tr>
<tr>
<td>$Q$</td>
<td>19,000</td>
<td>18,500</td>
<td>19,000</td>
</tr>
<tr>
<td>$\Delta f^*$</td>
<td>136 kc/sec</td>
<td>140 kc/sec</td>
<td>138 kc/sec</td>
</tr>
<tr>
<td>$\text{BW}^{**}$</td>
<td>$\ldots$</td>
<td>+2.7 $\text{Mc}/\text{sec}$</td>
<td>$\ldots$</td>
</tr>
</tbody>
</table>

| $\beta$   | 1.1         | $\ldots$  | $\ldots$    | 1.1          |
| $R_s$     | 37 $\text{M} \Omega/\text{m}$ | $\ldots$  | $\ldots$    | 30 $\text{M} \Omega/\text{m}$ |
| $Q$       | 31,000      | $\ldots$  | $\ldots$    | 20,000       |
| $\Delta f^*$ | 86 kc/sec   | $\ldots$  | $\ldots$    | 80 kc/sec    |
| $\text{BW}^{**}$ | $\ldots$  | $\ldots$  | $\ldots$    | $\ldots$ | -11.3 $\text{Mc}/\text{sec}$ |

* $\Delta f$ is the frequency perturbation of a 1/4 in diameter metal sphere at the center of a single cell.

** $\text{BW}$ is the band width defined here to be the difference in frequency between the "0" mode and the $\pi$ mode. The (+) sign is a forward wave, and the (-) sign is a backward wave.
designed for $\beta = 0.55$, and by stacking two such cells together, a cell for $\beta = 1.1$ was obtained. Spring rings were used to obtain electrical contact.

For the slotted iris, a plot of bandwidth vs. slot angle is shown in Fig. 2, and the corresponding shunt impedance vs. bandwidth is shown in Fig. 3. The values for the slotted iris cavity listed in Table I are for the optimum values of shunt impedance.

Also of interest in the case of the slotted irises, are the radial field variations. Both metal and dielectric spheres were pulled radially across the cavity. The electric field perturbation of the dielectric sphere was scaled to match the electric field perturbation of the metal sphere. Figures 4 and 5 are plots of the radial field taken along two different directions. The difference between the two curves is proportional to the magnetic field squared. A rotatable perturbation device was used to give a more accurate measurement of the circumferential field variation. At a radius of 0.75 in, measurements were made at various points along the length of the cell, and within the accuracy of the measuring equipment, the circumferential variation was less than 5%.

Tank flattening refers to the variation of electric field along the axis of the tank due to the tuning errors. These tuning errors are the results of machining tolerances, temperature variations, etc. It would be useful to obtain an analytic functional relationship relating the tuning
FIG. 1 SLOTTED IRIS
\[ \beta = 0.55 \]

**Fig. 2**

\( \phi \) (SLOT ANGLE - DEGREES)

BANDWIDTH (Mc)

\( \phi = 20^\circ \) to \( 50^\circ \)
\[ R_s \text{ m}\Omega/\text{meter} \]

\[ \beta = 0.55 \]

**FIG. 3**

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FIG. 5

RADIAL POSITION OF BEAD PATH

1/4" BRASS BALL

SCALD TEFLON BALL

+Δf

-Δf

Z CAVITY WALL

$\xi$ OF CAVITY
error to the properties of a structure, as has been done for a hollow cylindrical structure in the TM$_{010}$ mode. For iris-loaded structures the problem becomes extremely complex. The following is an experimental approach to the problem, in which various measurement techniques are used to derive an empirical relationship.

The tuning errors along the length of a cavity can be written as a Fourier series.

\[ F(z) = f_0 \sum_{n=1}^{\infty} \left( 1 + P_n \cos \frac{n\pi z}{L} \right) , \]  

(1)

where \( L \) is the length of the cavity and \( f_0 \) is the resonant frequency. Corresponding to the tuning error, there is an electric field variation, which can be written as

\[ E(z) = E_0 \sum_{n=1}^{\infty} \left( 1 + \epsilon_n \cos \frac{n\pi z}{L} \right) , \]  

(2)

where \( E_0 \) is the average electric field along the length of the cavity. We now want to find a functional relationship between \( P_n \) and \( \epsilon_n \), depending on the particular structure being considered. We first define the following function

\[ \epsilon_n = K F(L) G(n) \left( \frac{n}{L} \right) , \]  

(3)
and by various measurements show that Eq. (3) is valid and derive the quantities K, F(L), and G(n).

**Fig. 6**

In Fig. 6 is shown a cavity with 7 shaped irises, matched pickup loops and perturbation tuners in each cell. Figures 9 and 10 are photographs of the assembly. Operating at a frequency of 880 Mc/sec in the π mode at $\beta = 0.55$, the structure has a bandwidth of 2.7 Mc/sec and a Q of 18,500. (Bandwidth is defined here to be the difference in frequency between the 0-mode and the π-mode.) An rf drive loop was placed at the center of the cavity, and the tuners were adjusted to make the field flat (all eight pickup loops had the same output reading). From a previously determined tuning curve, the tuners were adjusted to obtain a first harmonic variation of the frequency along the cavity as in Fig. 7a. Figure 7b shows the variation of the electric field along the cavity, as measured at the pickup loops. From Fig. 7 we get the relations: $P_1 = \Delta f/f_0$ and $\varepsilon_1 = \Delta E/E_0$. Repeating the process for the 2nd, 3rd, and
4th harmonics, and substituting in Eq. (3), we obtain

\[
\frac{\varepsilon_1}{P_1} = KF(L_1)G(1) = 4550
\]

\[
\frac{\varepsilon_2}{P_2} = KF(L_1)G(2) = 2180
\]

\[
\frac{\varepsilon_3}{P_3} = KF(L_1)G(3) = 1140
\]

\[
\frac{\varepsilon_4}{P_4} = KF(L_1)G(4) = 825
\]

where \( L_1 = 0.80 \text{ m} \), the length of a seven-iris cavity. The above values can be approximately represented by the following relations:

\[
\frac{\varepsilon_n}{P_n} = KF(L_1)G(n) = \frac{KFL_1}{n^{1.2}}.
\]
Since $L_1$ is a constant for all of the above measurements

$$G(n) \approx \frac{1}{n^{1.2}}$$

We now want to determine the dependence on $L$ of the function $F(L)$. Consider a cavity of some arbitrary length $L$. The tuners are adjusted so that the frequency varies linearly along the cavity (i.e., has the shape of a ramp function) as shown in Fig. 8a. Figure 8b shows the corresponding electric field variation in the cavity. With the ramp-function variation, Eq. (1)

$$F(z) = f_0 \left[ 1 + P_1(\cos \frac{\pi z}{L} + \frac{1}{3^2} \cos \frac{3\pi z}{L} + \ldots ) \right]$$

may be written as

FIG 8
We have previously shown, from Eqs. (4) and (5) that 
\[ \varepsilon_n / P_n \propto 1/n^{1.2}, \]
and may therefore write Eq. (2) as:

\[ E(z) = E_0 \left[ 1 + \varepsilon_1 \left( \cos \frac{\pi z}{L} + \frac{1}{3^{3.2}} \cos \frac{3\pi z}{L} \right) + \frac{1}{5^{3.2}} \cos \frac{5\pi z}{L} + \ldots \right] \]  
(7)

At \( z = L \), Eqs. (6) and (5) become:

\[ F(L) = f_o \left[ 1 + P_1 \left( 1 + \frac{1}{3^2} + \frac{1}{5^2} + \ldots \right) \right] = f_o + \Delta f \]  
(8)

\[ E(L) = E_o \left[ 1 + \varepsilon_1 \left( 1 + \frac{1}{3^{3.2}} + \frac{1}{5^{3.2}} + \ldots \right) \right] = E_o + \Delta E \]  
(9)

where \( \Delta F \) and \( \Delta E \) are shown in Fig. 8.

From Eqs. (8) and (9) we may write:

\[ \frac{\Delta f}{f_o} = \frac{P_1 \left( 1 + \frac{1}{3^2} + \frac{1}{5^2} + \ldots \right)}{\varepsilon_1 \left( 1 + \frac{1}{3^{3.2}} + \frac{1}{5^{3.2}} + \ldots \right)} \approx 1.18 \frac{P_1}{\varepsilon_1}. \]  
(10)

From Eq. (4), for \( n = 1 \) and \( z = 1 \), we get
\[ F(L) = \frac{1}{P_1} \cdot \frac{1}{K} \]  

(11)

Substituting Eq. (1) in (11) we obtain

\[ F(L) = 1.18 \left( \frac{\Delta E}{E_o} \right) \cdot \frac{1}{K} = K_2 \left( \frac{\Delta E}{E_o} \right) \cdot \frac{1}{f_o} \]

(12)

For four different cavity lengths of 0.80, 0.70, 0.60, and 0.50 meters (corresponding to 7, 6, 5, and 4 irises, respectively), the tuners were adjusted to produce a ramp function frequency variation with \( \Delta f = 68 \) kc/sec. For each of the four cavity lengths, the electric field along the cavities was plotted, as shown in Fig. 8, and the values of \( E_o \) and \( \Delta E \) were found. Substituting the value of \( E_o, \Delta E, f_o \) and \( \Delta f \) in Eq. (12) we obtain: 
\( F(0.80) \approx 4800, F(0.70) \approx 3460, F(0.60) \approx 3000, \) and \( F(0.50) \approx 2000. \) The above \( F(L) \) values can be represented by the following approximation:

\[ F(L) \propto L^2 \]

(13)

Substituting Eqs. (5) and (8) into (3) we get

\[ \varepsilon_n = K_3 \frac{L^2}{n^{1.2}} P_n. \]

(14)

The independent numerical results from Eq. (3) can now be substituted in Eq. (14) to evaluate \( K_3. \)
Equation (14) becomes

\[ \epsilon_n = \frac{7500 \, L \, \frac{2}{n^{1.2}}}{P_n} \]  

(15)

The above measurements were made with a low-level signal generator (5 mW). With the calibrating equipment available, the probes and detectors may have an error of 5 to 10%.

It is interesting to note that for the narrow bandwidth (2.7 Mc/sec) structure measured above, the higher order harmonics go as \((n)^{-1.2}\). Similar measurements were made on a structure having a bandwidth of 40 Mc/sec, and it was found that the higher order harmonics varied as \((n)^{-2}\). It would be interesting to run a series of measurements on structures of different bandwidths, to evaluate the function

\[ \epsilon_n = \frac{K \, H(BW) \, F(L) \, G(n)}{n \, R(BW)} \, P_n. \]  

(16)

Unfortunately, time has not permitted this to be done.

Equation (15) clearly indicates the extreme tuning and stability requirements of the narrow band structure considered. Using short sections would obviously help the tank flattening problem but would increase the total number of individual cavities required. Another big improvement can be obtained with wider bandwidth structures, which would reduce the value of \(K_3\).

(The discussion following this paper has not been reproduced.)
References


A SHAPED IRIS FOR $\beta = 0.6$ AT $f = 880 \text{mc/s}$. THE HOLE DIA IS 2.111". THE STEEL SCALE IS 6" LONG. NOTE SPRING RING AT 10.125 DIA

FULL SPACER SECTION FOR $\beta = 0.6$. AT LOWER LEFT IS AN ADJUSTABLE TUNER. UPPER & LOWER RIGHT ARE COUPLING LOOPS

FIGURE 9
EXPLODED VIEW OF ONE CELL & END HALF CELL

ASSEMBLED FOUR CELL MODEL

FIGURE 10