AUG 17 1966

BNL 10376

BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.
Upton, L.I., N.Y.

AGSCD-11

ACCELERATOR DEPARTMENT
Internal Report

CFSTI PRICES

H.C. \$ 1.00; MN 50

MEASUREMENTS ON THE MULTISTEM DRIFT TUBE STRUCTURE
FOR PROTON ACCELERATORS

MASTER

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June 22, 1966

This is the second preliminary report on a new standing-wave structure, operating in the TM_{010} mode, for accelerating protons below an energy of 200 MeV. This structure employs more than one stem to support each drift tube, and unlike the conventional drift tube structure, the stems play a significant role in shaping the cavity fields. The first report¹ presented some measurements relating to the reduction of detuning effects obtained by the use of multiple stems. The purpose of this report is to describe in more detail the operating characteristics of a multistem structure.

The measurements were carried out on a cylindrical cavity, having a length of 36 in. and a diameter of 10.8 in. Of particular interest for the present discussion are the TM_{010} and TE_{110} modes. Figure 1 is a plot of these modes for the unloaded cavity. It should be noted that there are no modes below 650 Mc/sec (650 Mc/sec is the lowest frequency that energy can propagate down this structure).

Figure 2 shows a drift tube structure having a single stem support for each drift tube. This structure is scaled down from 200 Mc/sec for operation

1. S. Giordano, BNL Accelerator Dept. Int. Rpt. AGSCD-7, "A New Multistem, Drift-tube, Standing-wave, Zero-mode Proton Accelerating Structure," dated Feb. 25, 1966.

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at $\beta \approx 0.32$. The modes of this cavity are shown in Figure 3. A comparison between Figures 1 and 3 reveals a number of interesting differences. The addition of a single stem and drift tube decreases the frequency spacing between the $TE_{11\ell}$ and $TM_{01\ell}$ modes and in addition, introduces a new set of modes which we shall call the $TS(1)_{10\ell}$ modes, to be discussed in more detail later on. For modes designated $TS(N)$, N indicates the number of stems.

Now consider the structure shown in Figure 4, which is the same as that shown in Figure 2 with the exception that there are two stems, 180° apart. Figure 5 is a plot of the $TM_{01\ell}$, $TE_{11\ell}$ and $TS(2)_{10\ell}$ modes for the two-stem case. It is interesting to note that there is very little change in either the $TM_{01\ell}$ or the $TE_{11\ell}$ modes, as compared to the single-stem case, but the $TS(2)_{10\ell}$ modes are higher in frequency than the $TS(1)_{01\ell}$ modes.

Similar measurements were made on 3, 4 and 6 stem structures with configurations shown in Figure 6. For the 3, 4 and 6 stem cases it should be pointed out that the $TE_{11\ell}$ modes are all above 1200 Mc. The results for the $TM_{01\ell}$ and $TS(N)_{10\ell}$ modes for the 1, 2, 3, 4 and 6 stem cases are compiled in Figure 7.

The $TM_{01\ell}$ and $TE_{11\ell}$ modes are conventional modes and are discussed in many textbooks. The $TS(N)_{10\ell}$ or the more general $TS(N)_{nm\ell}$ modes are associated with transverse stem resonances and, as can be seen in Figure 7, the $TS(N)_{nm\ell}$ modes being considered are lower in frequency than the normal $TE_{11\ell}$ and $TM_{01\ell}$ modes. It should be pointed out that, to the author's knowledge, there is no mention in the literature of the $TS(N)_{nm\ell}$ modes and the associated bandpass.

To determine the nature of the $TS(N)_{nm\ell}$ modes, first consider a drift tube with a single stem in an open-ended, long, hollow cavity as shown in Figure 8a. Figure 8b shows the electric and magnetic field configurations for the $TS(1)_{10}$ mode. The values of N , m and n from Figure 8b correspond to $N = 1$ for a single stem, $m = 0$ since there is no radial variation of the field, and $n = 1$ since the radial electric field is zero at the stems and maximum mid-way between the stems. (There can exist higher order modes corresponding to $n > 1$, where the radial electric field goes to zero between stems.) For the case shown in Figure 8b, the electric field has a circumferential variation of

$$\left| \sin \frac{n\phi N}{2} \right| = \left| \sin \frac{\phi}{2} \right|.$$

Also shown in Figure 8b is the conduction current flowing on the stem. The single-stem transverse resonance for this case is 320 Mc/sec. This frequency is well below the normal $TE_{11\ell}$ and $TM_{01\ell}$ modes of the hollow guide and the fields from the transverse stem resonance decay exponentially along the guide.

Now consider a single drift tube with two stems (180° apart) in an open-ended, long, hollow cavity. The field configuration for the two-stem case is shown in Figure 8c, which corresponds to the $TS(2)_{10}$ mode, where $N = 2$ since there are two stems, and $n = 1$ since the circumferential field variation goes as

$$\left| \sin \frac{nN\varphi}{2} \right| = \left| \sin \varphi \right| .$$

The transverse resonant frequency for this case is 495 Mc/sec. It is interesting to note that the circumferential field variation does not change sign, as would be the case for a normal TE_{11} mode where the stem would be perpendicular to the transverse electric field. For the three-stem case shown in Figure 8d we have the $TS(3)_{10}$ mode, which has a resonant frequency of 610 Mc/sec. Figure 9 is a plot of transverse stem and drift tube resonant frequency vs. number of stems for a single drift tube in an open-ended cavity.

From measurements made using 1, 2, 3, 4 and 6 stems per drift tube in the cavity of Figure 2, it is seen from the results plotted in Figure 7 that the transverse $TS(N)_{10}$ stem resonance form a periodic coupled system having $TS(N)_{10\ell}$ resonances. As an example, a cavity having 6 drift tubes and three stems per drift tube has the following modes: $TS(3)_{101}$, $TS(3)_{102}$, $TS(3)_{103}$, $TS(3)_{104}$, $TS(3)_{105}$, $TS(3)_{106}$, corresponding to a phase shift per cell (a cell length being defined as the length between the center of two adjacent gaps) of $-\pi/6$, $-2\pi/6$, $-3\pi/6$, $-4\pi/6$, $-5\pi/6$, and $-6\pi/6$, respectively. The $TS(N)_{100}$ is a degenerate mode due to the boundary conditions, and cannot be excited. Also from Figure 7, the frequency of the TM_{010} mode is essentially unchanged and independent of the number of stems. The modes adjacent to the TM_{010} mode are affected by the stems, and it is these modes that determine the shape of the dispersion curve about the TM_{010} mode.

Various investigations have discussed the relative merits of "0", $\pi/2$, and π mode structures. To reduce beam loading and tank detuning effects, it is desirable to do either of the following:

1. In the "O" or "π" mode structure, make the quantity

$$\left| \frac{d^2 \omega}{d\beta^2} \right|$$

as large as possible. (The "O" and "π" modes are normally located at the end of a bandpass.)

2. For the $\pi/2$ mode (which is normally located at the center of a bandpass), make the quantity

$$\left| \frac{d\omega}{d\beta} \right|$$

as large as possible.

In Figure 7 it is seen that for the one and two-stem case the $TM_{01\ell}$ bandpass remains relatively unaffected by the $TS(N)_{10\ell}$ bandpass. In going to 3, 4, or 6 stems the $TM_{01\ell}$ bandpass is influenced by the $TS(N)_{10\ell}$ bandpass. At some region between 4 and 6 stems it may be possible to have the $TS(N)_{01\ell}$ and $TM_{01\ell}$ bandpasses join together and form a continuous dispersion curve, in which case, if possible, the behavior of the TM_{010} mode would be more like a $\pi/2$ mode.

The six-stem case, as seen in Figure 7, is obviously an overcompensated case and will not be discussed at the present time. The four-stem case is obviously undercompensated. The desired operating point should therefore be between four and six stems. The transverse stem resonances (Figure 9) for the four and six stem cases are 700 and 800 Mc/sec respectively. The desired operating point may more appropriately be described as being where the transverse stem resonance is somewhere between 700 and 800 Mc. The transverse stem resonance is a function of the number of stems and also the width of the stems. The measurements shown in Figure 9 were made with stems having a diameter of $\frac{1}{2}$ in. Sheet metal tabs were added to the stem, as shown in Figure 10, and the flare F was varied from $\frac{1}{2}$ in. to $3\frac{1}{2}$ in. Figure 11 shows the transverse stem resonance vs. number of stems for different flare widths.

Figure 12 is a plot of the $TM_{01\ell}$ and $TS(N)_{01\ell}$ modes for a four-stem structure with stem flares of $\frac{1}{2}$ in., $\frac{1}{2}$ in. and $3/4$ in. Also plotted in Figure 12 are the $TM_{01\ell}$ modes for a single stem. It is interesting to note the change in the shape of the dispersion curve in going from a one stem to the four stem,

and the change in going from a $\frac{1}{2}$ in. flare to a $\frac{3}{4}$ in. flare.

As previously reported in AGSCD-7, for the case of a four-stem, $\frac{1}{2}$ in.-flare structure, tank detuning effects were reduced by a factor of 4. Some preliminary measurements on a four-stem structure having a flare of $\frac{3}{4}$ in. indicate tank detuning effects can be reduced by a factor of 10 or greater.

This work was performed with a scaled model, representing a section of linac at 50 MeV. A scaled model is presently being constructed to represent a section of linac at 1 MeV. There is some concern as to the effect that the additional stems and $TS(N)_{10}$ modes will have on shunt impedances of the accelerating mode. Some very preliminary measurements indicate that the reduction in shunt impedance is small and represents basically the extra losses introduced by the additional stems.

I would like to thank Mr. Hannwacker for the work of taking the above measurements, and Drs. J.P. Blewett and G.W. Wheeler and Mr. Hannwacker for their helpful discussions.

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Distr.: AGSCD External

Figure 1. Hollow Cylindrical Cavity

$L = 6''$
 $D = 8''$
 $d = 1.5''$
 $l = 3.6''$

Figure 2. Single Stem Drift Tube Cavity.

Figure 3. Modes of the Single Stem Drift Tube Cavity.

$$L = 6''$$

$$D = 8''$$

$$d = 1.5''$$

$$l = 3.6''$$

Figure 4. Two Stem (180°) Drift Tube Cavity.

Figure 5. Modes of the Two Stem (180°) Drift Tube Cavity.

3-Stem

4-Stem

6-Stem

Figure 6. Multistem Configurations.

Figure 7. Modes of Multistem Drift Tube Cavities.

Figure 8. Stem Resonances

Fig. 9. Transverse stem and drift tube resonances of a single drift tube in a long, open-ended cavity ($\frac{1}{4}$ " diameter stems).

Figure 10. Flared Stems.

Fig. 11. Transverse stem and drift tube resonances for a flared stem.

Figure 12. Four stems with flares.