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THE BALL TUNER CHANGE TABLES

MASTER

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Tables have been computed which give the amounts by which to change the linac ball tuner settings to produce changes in the field of the form

$$\sum_{n=1}^3 A_n \cos \frac{n\pi z}{L}$$

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This report gives the construction of the tables and some comments on their use.

The ball tuner change tables were computed from the relation which is derived in JLW-1 as equation (12).

$$\frac{r_o(z)}{a_o} = 1 + \frac{\sum_{n=0}^{\infty} \frac{A_n}{A_o} \left(\frac{n^2}{8N^2} \right) \cos \frac{n\pi z}{L}}{\sum_{n=0}^{\infty} \frac{A_n}{A_o} \cos \frac{n\pi z}{L}} \quad (1)$$

$r_o(z)$ is the effective radius of the cavity wall; a_o is the radius of the uniform cavity of the same frequency; A_n is the n th Fourier component of the measured field; N is the length of the cavity in wavelengths, i.e., $N = L/\text{wavelength}$ where L is the length.

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Substituting the value of $8N^2$ for our linac, assumed to be an empty cavity, gives for the fraction part of (1), which is the variation in radius,

$$\frac{(.000257) \sum_{n=1}^{\infty} \frac{A_n}{A_0} n^2 \cos \frac{n\pi z}{L}}{1 + \sum_{n=1}^{\infty} \frac{A_n}{A_0} \cos \frac{n\pi z}{L}}$$

Frequency is proportional to radius so that the equivalent frequency shift as a function of z is obtained simply by multiplying the above expression by 201 Mc.

$$\Delta f(z) = \frac{51.4 \sum_{n=1}^{\infty} \frac{A_n}{A_0} n^2 \cos \frac{n\pi z}{L}}{1 + \sum_{n=1}^{\infty} \frac{A_n}{A_0} \cos \frac{n\pi z}{L}} \text{ kilocycles} \quad (2)$$

From the experimental curves of the frequency of each linac section as a function of ball tuner position when all tuners move in unison, the following tuning sensitivities in the region of 201 Mc are found. The units are kilocycles per 100 numbers change on the ball tuner counters; 100 numbers equals 3/4 inch motion.

Tank No.	Kc/100	Ball Tuner Diameters (inches)									
1	58	5	5	5	5	5	5	5	5		
2	48	5	5	5	5	5	5	5	5 1/2	46.1	61.3
3	58	5 1/2	5 1/2	5 1/2	5 1/2	5 1/2	5 1/2	5 1/2			
4	42	5 1/2	5 1/2	5 1/2	5 1/2	5 1/2					
5	65	5 1/2	5 1/2	5 1/2	5 1/2	5 1/2					
6	55	5 1/2	5 1/2	5 1/2	5 1/2	5 1/2					
7	53	5 1/2	5 1/2	5 1/2	5 1/2						
8	48	5 1/2	5 1/2	5 1/2	5 1/2						
9	60	5 1/2	5 1/2	5 1/2	6					55.8	57.6

contd.

Tank No.	Kc/100	Ball Tuner Diameters (inches)							
10	66	5 $\frac{1}{2}$	6	6	6			54.0	70.0
11	53	6	6	6					

The last two columns give the individual tuner capabilities for the tanks with unequal ball diameters assuming the effectiveness is proportional to the volume. Dividing equation (2) by these frequency values then converts it to have the dimension of ball tuner number change. Expressing A_n/A_0 as a percent multiplies out the 100 in the per 100 numbers of the above table.

The distances of the ball tuners from the low energy end were computed from data given on D07-769-5D and are repeated here for reference. (See Table II.)

These distances are the values of z in equation (2) for which the tables are computed.

The tables consist of 6 pages. The first three pages give values of ball tuner change for entries of ball tuner number and percent of harmonic, and the three pages are for the three harmonics. The second three pages are entered in the same way and give a correction factor for use when large changes are made. For example, the second row, third column of the $n = 2$ page gives the term of the numerator of (2) for $A_n/A_0 = 3\%$, for $z =$ the distance of ball tuner 12, and for $n = 2$, this value divided by 48, which is the tuning effectiveness of tuner 12. The corresponding element on the fifth page is the term of the sum in the denominator for these A_n/A_0 , z , and n values.

The tables give a number (sometimes negative) to be added to each ball tuner, which will produce the field variation

$$\Delta H = \sum_{n=1}^3 \frac{A_n}{A_0} \cos n\pi z$$

with z increasing from the low to high energy end. This polarity question can be resolved by remembering, "Increasing field with increasing numbers". Actually with increasing numbers, the ball tuner radial position decreases, the frequency decreases, which means the effective radius increases.

The positive shapes for the three harmonics are sketched below,

If measurement showed a field pattern like

This would be a negative 2nd harmonic error, which would call for a positive correction. It has a magnitude of 5%. Entering the $n = 2$ table in the 5% column, one finds for ball tuner number 11, which is the first tuner in tank 1, the number 17.6. This is the number to be added to this ball tuner. The $n = 2$ correction factor table indicates a 5% reduction in the value of 17.6, which would be rounded off to 17 or 18. The correction factor would be too small to bother with in this case.

If a measured field pattern is Fourier analyzed into the three harmonics, the procedure would be to add the numbers (paying attention to sign) from the first three pages, add the numbers from the last three pages, and then divide the total change number by one plus the total correction percent. The correction need be used only for large changes.

The IBM computer was programmed with the help of D.S. Robertson and A. Maschke to print out the tables in a format that could be used directly, and this copy is in the linac control room. On following pages are copied the 1% columns of the tables. Work sheets for use with the tables have been made up.

A simpler $n = 1$ and 2 , version of this tank flattening method has been tried with fair success except that the corrections seemed to be too large. If a 5 % correction appears to be called for, entering the tables for 3% gives a better result. Present probe patterns do not permit much precision in determining the Fourier components. The $n = 3$ values have not been tried conclusively as yet; they will probably have to be reduced also.

The empty cavity theory gives the frequency spacings for the first three axial modes at 56 Kc, 224 Kc, and 504 Kc. The first mode in our linac usually appears at about 30 Kc. Higher modes are difficult to identify. The last measurement, made in November 1961 showed resonances of the linac at 26, 87, 195, 260, and 502 Kc above the flat mode, where 26 Kc was the first mode. This would be the mode spacing of a cavity $\sqrt{\frac{56}{26}}$ longer than our linac assumed empty, and hence, the ball tuner change number would be $26/56$ times that called for our (empty) linac. With a greater number of probes capable of greater precision, it might be possible to identify these higher modes and to make up another set of tables which would give better results. Of course, better probe measurements will allow a closer evaluation of the present tables.

On the following pages are:

1. The ball tuner change numbers for 1% correction (Table I).
2. The z values of the ball tuners and other values used in making up the tables (Table II).

BALL TUNER CHANGE TABLES

TABLE I

Ball Tuner Number	Ball Tuner Change Numbers for 1%			Ball Tuner Number	1	2	3
	n = 1	2	3				
11	.885	3.53	7.78	81	-.485	-2.52	9.50
12	.883	3.48	7.70	82	-.575	-1.987	9.61
13	.88	3.45	7.50	83	-.671	-1.408	9.25
14	.876	3.40	7.15	84	-.690	-.746	8.34
15	.873	3.31	6.80	91	-.640	-.1283	6.07
16	.868	3.24	6.45	92	-.668	+.216	5.29
17	.862	3.16	6.05	93	-.715	.775	3.71
18	.856	3.07	5.60	94	-.582	1.046	1.315
21	1.04	3.57	5.95	101	-.826	1.945	-.1797
22	1.03	3.40	5.20	102	-.655	1.73	-1.03
23	1.02	3.23	4.38	103	-.677	2.07	-2.43
24	1.005	3.02	3.44	104	-.700	2.39	-3.94
25	.99	2.78	2.47	111	-.946	3.59	-5.83
26	.972	2.55	1.436	112	-.962	3.74	-8.0
27	.955	2.28	.334	113	-1.02	3.87	-8.66
28	.72	1.52	-.59				
31	.726	1.217	-2.07				
32	.705	.920	-3.02				
33	.681	.628	-3.98				
34	.655	.309	-5.04				
35	.628	0	-5.64				
36	.596	-.352	-6.39				
41	.757	-1.18	-10.02				
42	.705	-1.68	-10.6				
43	.652	-2.12	-10.81				
44	.597	-2.57	-11.0				
45	.538	-3.00	-10.75				
51	.308	-2.20	-6.64				
52	.266	-2.45	-6.10				
53	.222	-2.66	-5.35				
54	.177	-2.86	-4.45				
55	.131	-3.00	-3.40				
61	.0982	-3.65	-2.60				
62	.0673	-3.69	-1.745				
63	.00737	-3.75	-.218				
64	-.051	-3.67	1.353				
65	-.1146	-3.64	3.00				
71	-.181	-3.62	4.66				
72	-.245	-3.38	6.07				
73	-.311	-3.07	7.26				
74	-.377	-2.70	8.13				

TABLE OF LINAC BALL TUNER DISTANCES FROM LOW ENERGY END AND RELATED NUMBERS

TABLE II

1	2	3	4	5	6	7	8	9
11	21.5	2.95	5.91	8.85	.998	.995	.988	58
12	36.2	4.97	9.94	14.91	.996	.984	.966	
13	48.5	6.66	13.32	19.98	.993	.973	.940	
14	62.0	8.52	17.05	25.56	.989	.956	.899	
15	76.7	10.61	21.1	31.52	.983	.933	.853	
16	87.2	11.98	23.95	36	.978	.914	.809	
17	98.2	13.50	27.0	40.5	.972	.891	.760	
18	109.8	15.08	30.2	45.24	.966	.864	.704	58
21	128.1	17.58	35.2	52.74	.953	.817	.605	47
22	141.1	19.40	38.8	58.2	.943	.779	.527	
23	154.5	21.2	42.5	63.6	.932	.737	.445	
24	168.5	23.15	46.3	69.45	.919	.691	.350	
25	183.0	25.15	50.3	75.45	.905	.639	.250	
26	198.0	27.2	54.4	81.6	.889	.582	.146	
27	213.6	29.35	58.7	88.05	.871	.519	.034	47
28	229.7	31.50	63.1	94.5	.853	.452	-.078	61
31	254.9	35.0	70	105	.819	.342	-.259	58
32	272.3	37.4	75	112.2	.794	.259	-.378	
33	290.3	39.9	79.8	120	.767	.177	-.500	
34	308.9	42.4	85	129.2	.738	.087	-.632	
35	327.9	45	90	135	.707	.000	-.707	
36	347.5	47.7	95.6	143.1	.673	-.099	-.799	58
41	378.0	51.9	104	156	.617	-.241	-.914	42
42	398.9	54.8	110	164.4	.576	-.342	-.963	
43	420.4	57.8	115.6	173.4	.533	-.432	-.993	
44	442.4	60.8	121.6	182.4	.488	-.524	-.999	
45	465.0	63.9	127.8	192	.440	-.613	-.978	42
51	488.1	67.1	134.2	201	.389	-.697	-.934	65
52	511.8	70.3	140.6	211	.337	-.772	-.857	
53	535.9	73.7	147.4	221.1	.280	-.842	-.754	
54	560.6	77.1	154.2	231.3	.223	-.902	-.625	
55	585.9	80.5	161	241.5	.165	-.946	-.477	65
61	611.7	84.0	168	252	.105	-.978	-.309	55
62	624.7	85.9	171.8	258	.072	-.989	-.208	
63	651.3	89.5	179	268.5	.008	-.999	-.026	
64	678.4	93.1	186.2	279.3	-.054	-.994	+.161	
65	706.0	97.0	194	291	-.122	-.970	.358	55
71	734.2	100.8	201.6	302.4	-.187	-.934	.535	53
72	762.8	104.7	209.4	314.1	-.253	-.871	.696	
73	792.0	108.8	217.6	326.4	-.322	-.791	.833	
74	821.8	112.9	225.8	339	-.389	-.697	.934	53

TABLE II - contd.

1	2	3	4	5	6	7	8	9
81	852.0	117	234	351	-.454	-.588	.988	48
82	882.8	121.2	242.4	3.6	-.518	-.463	.998	
83	914.0	125.4	250.8	16.2	-.607	-.328	.960	
84	946.0	130	260	30	-.643	-.174	.866	48
91	978.1	134.2	268.4	42.6	-.697	-.035	.736	56
92	994.5	136.7	273.4	50.1	-.727	+.059	.641	56
93	1027.5	141.1	282.2	63.3	-.778	.211	.449	56
94	1061.1	145.9	291.8	78	-.828	.371	.208	73
101	1095.2	150.4	300.8	91.2	-.869	.512	-.021	54
102	1112.5	153.0	306.0	99	-.891	.588	-.156	70
103	1147.3	157.2	314.8	111.6	-.922	.705	-.368	70
104	1182.7	162.2	324.4	126.6	-.952	.813	-.596	70
111	1218.5	167.2	334.4	141.6	-.975	.923	-.784	53
112	1254.9	172.2	344.4	156.6	-.991	.963	-.918	53
113	1291.7	177.3	354.6	171.9	-.999	.996	-.990	53

Column description:

- 1 Ball tuner number
- 2 Distance in inches from L.E. end plate = z.
- 3 180z/1311
- 4 360z/1311
- 5 540z/1311
- 6,7,8 are cosines of 3,4,5.
- 9 kc/100 numbers

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Distribution AD B1 Ltd. and Argonne