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R.F. bucket area

J. G. Cottingham

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Collider Accelerator Department
Brookhaven National Laboratory

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R. F. BUCKET AREA

Booster Technical Note
No. 31

J. G. COTTINGHAM

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ACCELERATOR DEVELOPMENT DEPARTMENT
Brookhaven National Laboratory
Upton, N.Y. 11973

In order to optimize the Booster Magnet Cycle the magnet field versus time function must be determined. If the field rises too fast the r.f. bucket area is reduced. Conversely, if the field rises too slowly too much time is wasted in a very crowded time cycle. A key input to this optimization process is the magnet field versus time function that keeps the r.f. accelerating bucket area constant.

I have computed this function using the following 2,3.

$$\text{r.f. Bucket area} = \frac{8C}{\pi ch} \alpha(\phi_s) \left[\frac{eV E_0 \gamma}{2\pi Mh |\eta|} \right]^{1/2}$$

$$\text{where: } \beta^2 = 1 - \frac{E_0^2}{E^2}$$

$$\gamma = E/E_0$$

$$\eta = \frac{1}{v_h^2} - \frac{1}{\gamma^2}$$

E_0 - rest energy of protons

T - Kinetic energy

E - $T + E_0$

V - r.f. crest voltage

M = ratio - mass/charge

h = harmonic No.

v_h = horizontal nu (4.82)

ϕ_s - stable phase angle

$\alpha(\phi_s)$ - ratio - see Table I

C - machine circumference

c - velocity of light

e - electronic charge

Using a selected r.f. bucket area the computing process proceeds as follows:

1. For a set of machine inputs the desired value of α (ϕ s) was determined.
2. From the value of α (ϕ s) the stable phase angle ϕ s is obtained.
3. From the stable phase angle the energy gain per turn is computed.
4. From the energy gain per turn (per unit of time) the rate of magnet field rise is computed.
5. This process is iterated to generate the field-time function.
2.4 millisecc. Steps were used in this integration.

The results are plotted in figures 1 and 2 for r.f. accelerating crest voltages of 44 and 48KV respectively. These figures also contain the initial and final dB/dT values for chosen r.f. bucket areas.

Figure 1 contains a dashed curve which represents a constant (dB/dT)B curve which has been passed through the beginning and end points of the area equal leV-sec. curve. This function has sometimes been used to estimate the constant bucket area function when this information is missing. But, as one can see the approximation is not good. The correct curve starts with a smaller slope but finished with a higher slope. Unfortunately, more power is required to follow the correct curve than is required to follow the approximation.

References:

- 1) Bovet, Gouiran, Gumowski and Reich A Selection of Formulae and Data Useful for the Design of the A.G. Synchrotrons, Cern/MPS-SI/Int. D1/70/4 23 April, 1970.
- 2) Cole and Morton, Area and Bunching Factors of Partially Filled Buckets, UCID 10130 AS/Theoretical/02 Sept 21, 1984; LRL, Univ. of California.
- 3) RUGGIERO and Young, Booster r.f. Program for Heavy Ions, RHIC-AP-17, Brookhaven National Lab. May 31, 1985.

Table I (1)

RP "BUCKET" WIDTH, NORMALISED (HALF) HEIGHT AND AREA

(From Ref. 14; note that in this reference $Y(0) = \phi_{\max}(0) [\sqrt{2} \pi v_0(0)] = \sqrt{2}$ - rather than 2 - for computational convenience. See page 31 for other definitions and a graphical representation.)

All values of $\phi_s, \phi_1, \phi_2, \Delta\phi$ in degrees

$\alpha (0)$

Stable phase	"Bucket" width			Half height		Area $\alpha = \frac{A(\Gamma)}{A(0)}$
	Γ	ϕ_1	ϕ_2	$\Delta\phi$	$Y(\Gamma)$	
0	0.000000	-180.0	180	360	1.414214	1.000000
1	0.17452	-154.0	179	333	1.394803	.986275
2	0.34859	-143.5	178	321	1.375347	.972517
3	0.52336	-135.5	177	312	1.355847	.958729
4	0.69756	-128.8	176	305	1.336309	.944913
5	0.87156	-122.9	175	298	1.316736	.931073
6	1.04528	-117.6	174	292	1.297132	.917211
7	1.21869	-112.6	173	286	1.277500	.903329
8	1.39173	-108.1	172	280	1.257846	.889431
9	1.56434	-103.7	171	275	1.238171	.875519
10	1.73648	-99.6	170	270	1.218482	.861597
11	1.90809	-95.7	169	265	1.198781	.847666
12	2.07912	-92.0	168	260	1.179072	.833730
13	2.24951	-88.4	167	255	1.159360	.819791
14	2.41922	-84.9	166	251	1.139648	.805853
15	2.58819	-81.5	165	247	1.119940	.791917
16	2.75637	-78.2	164	242	1.100240	.777987
17	2.92372	-75.0	163	238	1.080552	.764066
18	3.09017	-71.9	162	234	1.060881	.750156
19	3.25568	-68.9	161	230	1.041230	.736261
20	3.42020	-65.9	160	226	1.021603	.722382
21	3.58368	-63.0	159	222	1.002004	.708524
22	3.74607	-60.1	158	218	.982438	.694688
23	3.90731	-57.3	157	214	.962907	.680878
24	4.06737	-54.5	156	210	.943418	.667097
25	4.22618	-51.8	155	207	.923972	.653347
26	4.38371	-49.1	154	203	.904576	.639632
27	4.53990	-46.4	153	199	.885232	.625954
28	4.69472	-43.8	152	196	.865945	.612316
29	4.84810	-41.2	151	192	.846719	.598721
30	5.00000	-38.7	150	189	.827559	.585172
31	5.15030	-36.2	149	185	.808467	.571673
32	5.29919	-33.7	148	182	.789450	.558225
33	5.44639	-31.2	147	178	.770510	.544833
34	5.59183	-28.6	146	175	.751653	.531499
35	5.73576	-26.3	145	171	.732882	.518226
36	5.87785	-23.9	144	168	.714202	.505017
37	6.01815	-21.6	143	165	.695618	.491876
38	6.15661	-19.2	142	161	.677132	.478805
39	6.29320	-16.9	141	158	.658751	.465807
40	6.42800	-14.6	140	155	.640464	.452872
41	6.56059	-12.3	139	151	.622256	.440000
42	6.69121	-10.0	138	148	.604121	.427188
43	6.81998	-7.7	137	145	.586161	.414436
44	6.94698	-5.4	136	141	.568296	.401744
45	7.07167	-3.2	135	138	.550532	.389113
46	7.19340	-1.0	134	135	.532868	.376544
47	7.31354	1.2	133	132	.515304	.364136
48	7.43145	3.5	132	129	.497841	.351789
49	7.54710	5.6	131	125	.480478	.339504
50	7.66044	7.8	130	122	.463115	.327280
51	7.77146	10.0	129	119	.445752	.315117
52	7.88011	12.2	128	116	.428389	.303015
53	7.98636	14.3	127	113	.411026	.290974
54	8.09017	16.4	126	110	.393663	.279004
55	8.19152	18.6	125	106	.376300	.267104
56	8.29038	20.7	124	103	.358937	.255274
57	8.38671	22.8	123	100	.341574	.243514
58	8.48046	24.9	122	97	.324211	.231824
59	8.57167	27.0	121	94	.306848	.220304
60	8.66025	29.1	120	91	.289485	.208954
61	8.74620	31.2	119	88	.272122	.197774
62	8.82948	33.3	118	85	.254759	.186764
63	8.91007	35.4	117	82	.237396	.175924
64	8.98754	37.4	116	79	.220033	.165254
65	9.06201	39.5	115	75	.202670	.154754
66	9.13454	41.6	114	72	.185307	.144424
67	9.20505	43.6	113	69	.167944	.134254
68	9.27354	45.7	112	66	.150581	.124244
69	9.33980	47.7	111	63	.133218	.114394
70	9.39965	49.7	110	60	.115855	.104704
71	9.45519	51.8	109	57	.108492	.095174
72	9.50573	53.8	108	54	.101129	.085804
73	9.55635	55.8	107	51	.093766	.076594
74	9.61262	57.9	106	48	.086403	.067544
75	9.66526	59.9	105	45	.079040	.058654
76	9.72050	61.9	104	42	.071677	.049924
77	9.77370	63.9	103	39	.064314	.041354
78	9.83148	65.9	102	36	.056951	.032944
79	9.88627	68.0	101	33	.049588	.024684
80	9.94800	70.0	100	30	.042225	.016574
81	9.97688	72.0	99	27	.034862	.008624
82	9.99248	74.0	98	24	.027500	.001874
83	9.99546	76.0	97	21	.020138	.000424
84	9.99522	78.0	96	18	.012776	.000174
85	9.99155	80.0	95	15	.005414	.000074
86	9.99524	82.0	94	12	.001852	.000024
87	9.99630	84.0	93	9	.000690	.000012
88	9.99351	86.0	92	6	.000228	.000006
89	9.99848	88.0	91	3	.000076	.000003
90	1.000000	90.0	90	0	.000000	.000000

Stable phase	"Bucket" width			Half height		Area $\alpha = \frac{A(\Gamma)}{A(0)}$
	Γ	ϕ_1	ϕ_2	$\Delta\phi$	$Y(\Gamma)$	
0	0.642788	-14.6	160	155	.640479	.452887
1	6.56059	-12.3	139	151	.622319	.440046
2	6.69121	-10.0	138	148	.604277	.427288
3	6.81998	-7.7	137	145	.586357	.414617
4	6.94698	-5.4	136	141	.568564	.402035
45	7.07167	-3.2	135	138	.550902	.389546
46	7.19340	-1.0	134	135	.533376	.377154
47	7.31354	1.2	133	132	.515991	.364861
48	7.43145	3.5	132	129	.498752	.352671
49	7.54710	5.6	131	125	.481664	.340588
50	7.66044	7.8	130	122	.464732	.328615
51	7.77146	10.0	129	119	.447960	.316755
52	7.88011	12.2	128	116	.431354	.305013
53	7.98636	14.3	127	113	.414919	.293392
54	8.09017	16.4	126	110	.398660	.281895
55	8.19152	18.6	125	106	.382583	.270527
56	8.29038	20.7	124	103	.366694	.259292
57	8.38671	22.8	123	100	.350997	.248192
58	8.48046	24.9	122	97	.335499	.237234
59	8.57167	27.0	121	94	.320206	.226420
60	8.66025	29.1	120	91	.305123	.215755
61	8.74620	31.2	119	88	.290258	.205243
62	8.82948	33.3	118	85	.275616	.194890
63	8.91007	35.4	117	82	.261203	.184699
64	8.98754	37.4	116	79	.247028	.174675
65	9.06201	39.5	115	75	.233096	.164824
66	9.13454	41.6	114	72	.219416	.155150
67	9.20505	43.6	113	69	.205994	.145660
68	9.27354	45.7	112	66	.192844	.136358
69	9.33980	47.7	111	63	.179960	.127251
70	9.39965	49.7	110	60	.167365	.118345
71	9.45519	51.8	109	57	.155063	.109646
72	9.50573	53.8	108	54	.143065	.101162
73	9.55635	55.8	107	51	.131380	.092900
74	9.61262	57.9	106	48	.120020	.084867
75	9.66526	59.9	105	45	.108998	.077073
76	9.72050	61.9	104	42	.098325	.069526
77	9.77370	63.9	103	39	.088017	.062237
78	9.83148	65.9	102	36	.078089	.055217
79	9.88627	68.0	101	33	.068558	.048478
80	9.94800	70.0	100	30	.059444	.042033
81	9.97688	72.0	99	27	.050769	.035899
82	9.99248	74.0	98	24	.042558	.030093
83	9.99546	76.0	97	21	.034841	.024636
84	9.99522	78.0	96	18	.027654	.019554
85	9.99155	80.0	95	15	.021041	.014878
86	9.99524	82.0	94	12	.015058	.010647
87	9.99630	84.0	93	9	.009781	.006916
88	9.99351	86.0	92	6	.005325	.003765
89	9.99848	88.0	91	3	.001883	.001331
90	1.000000	90.0	90	0	.000000	.000000

Crest R.F. Volts = 44 KV

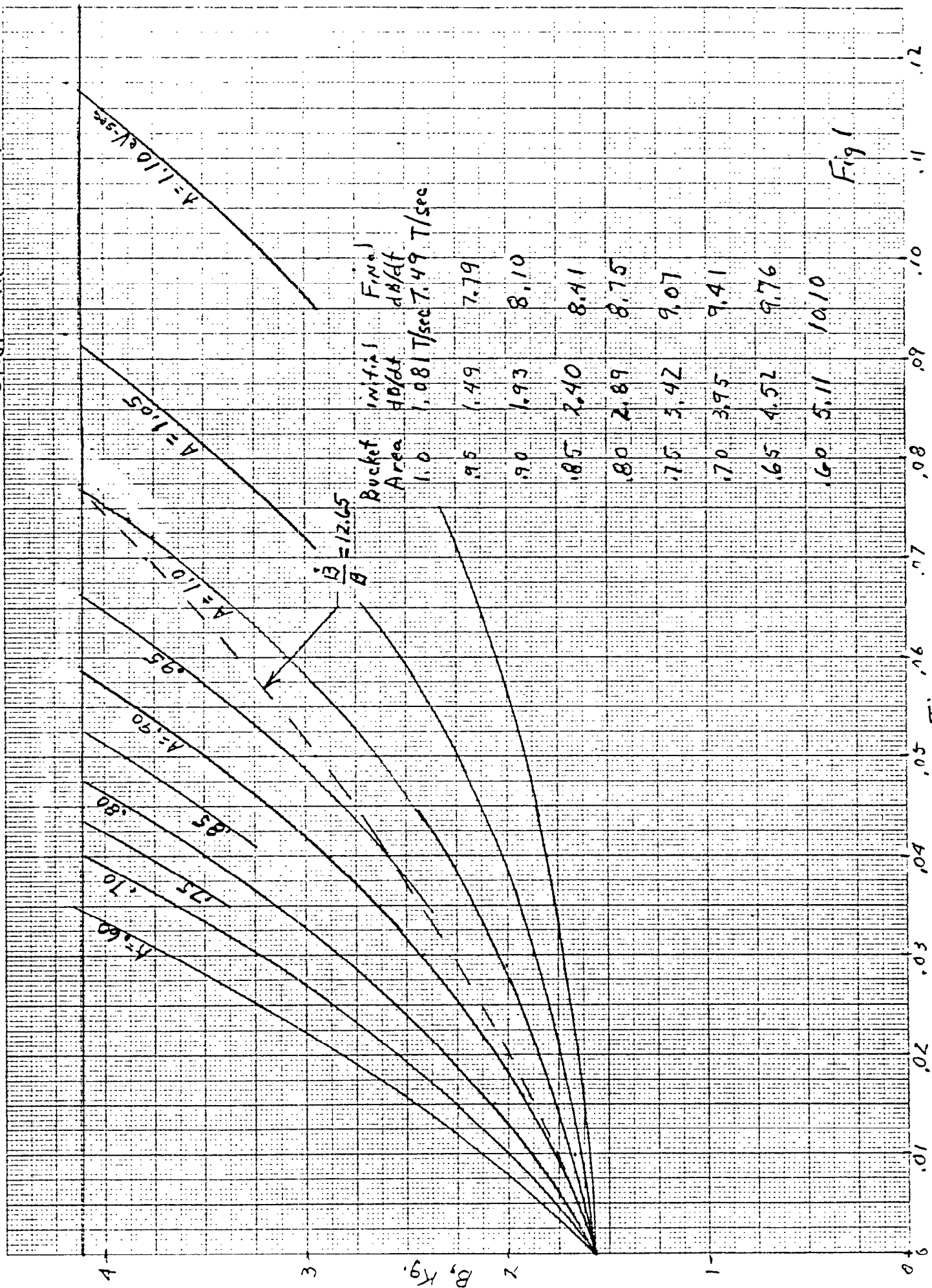


Fig 1

Crest R.F. Volts = 48 KV

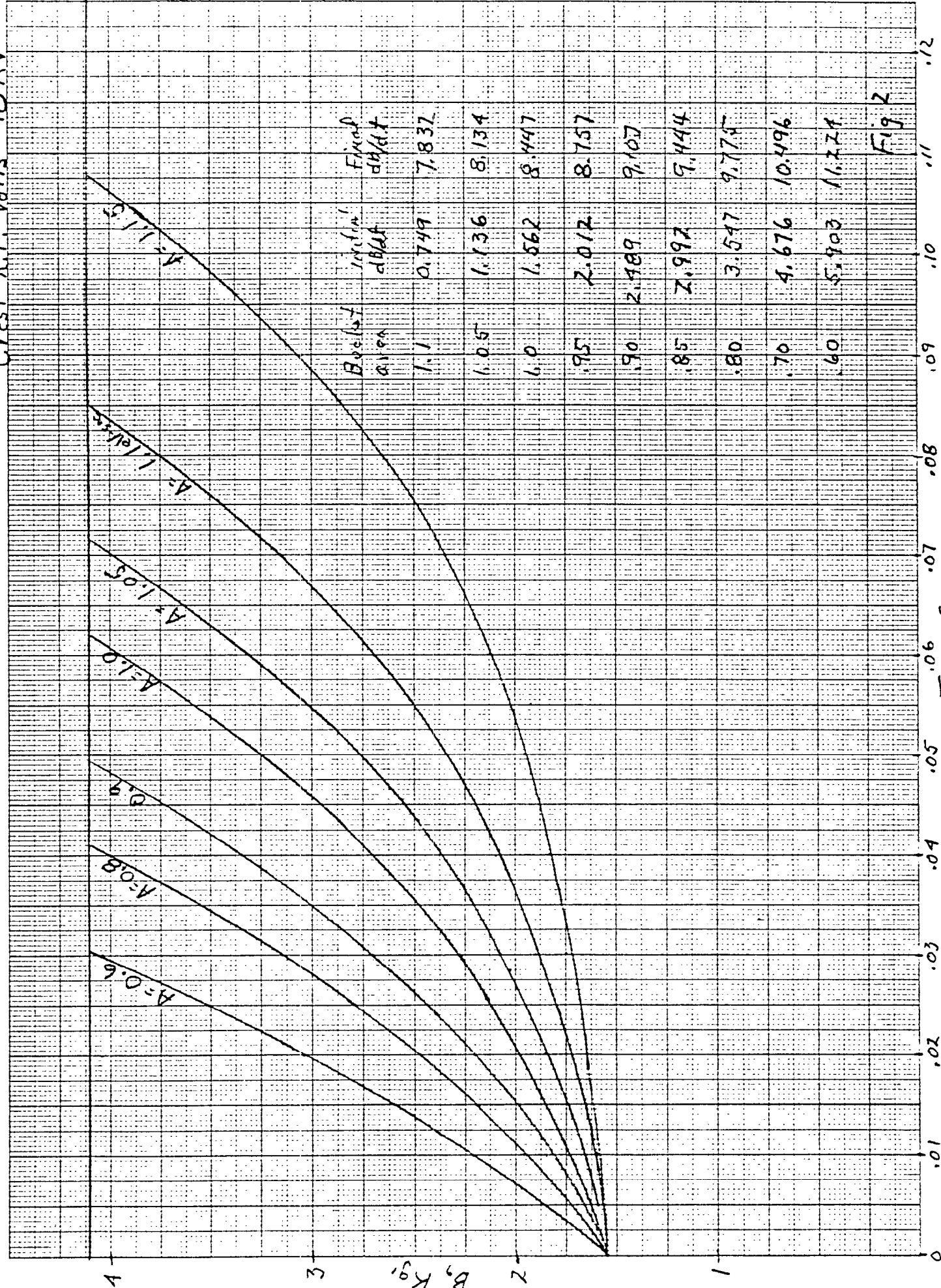


Fig 2