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R.F. bucket area

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Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC)

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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].

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

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

$$\gamma = E/E_o$$

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

E_o - rest energy of protons

T - Kinetic energy

E - $T + E_o$

V - r.f. crest voltage

M = ratio - mass/charge

h = harmonic No.

ν_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 millisec. 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. Dl/70/4 23 April, 1970.

2) Cole and Morton, Area and Bunching Factors of Partially Filled Buckets, UCID 10130 AS/Theorical/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.

APPENDIX D

Table I (1)

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

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

All values of φ_s, φ_1, φ_2, $\Delta\varphi$ in degrees

$\alpha(\Phi_s)$

Stable phase φ_s	Γ	"Bucket" width φ_1	φ_2	$\Delta\varphi$	Half height $Y(\Gamma)$	$\beta = \frac{\Delta E(\Gamma)}{\Delta E(0)}$	Area $\alpha = \frac{A(\Gamma)}{A(0)}$
0	0.000000	-180.0	180	360	1.414214	1.000000	1.000000
1	.017452	-154.0	179	333	1.394803	.986275	.954105
2	.034899	-143.5	178	321	1.375347	.972517	.917558
3	.052336	-135.5	177	312	1.355847	.958729	.884511
4	.069756	-128.8	176	305	1.336309	.944913	.853741
5	.087156	-122.9	175	298	1.316736	.931073	.824676
6	.104528	-117.6	174	292	1.297132	.917211	.796983
7	.121869	-112.6	173	286	1.277500	.903329	.770443
8	.139173	-108.1	172	280	1.257846	.889431	.744906
9	.156434	-103.7	171	275	1.238171	.875519	.720257
10	.173648	-99.6	170	270	1.218482	.861597	.696413
11	.190809	-95.7	169	265	1.198781	.847666	.673303
12	.207912	-92.0	168	260	1.179072	.833730	.650875
13	.224951	-88.4	167	255	1.159360	.819791	.629082
14	.241922	-84.9	166	251	1.139648	.805853	.607888
15	.258819	-81.5	165	247	1.119940	.791917	.587261
16	.275637	-78.2	164	242	1.100240	.777987	.567174
17	.292372	-75.0	163	238	1.080552	.764066	.547603
18	.309017	-71.9	162	234	1.060881	.750156	.528529
19	.325568	-68.9	161	230	1.041230	.736261	.509933
20	.342020	-65.9	160	226	1.021603	.722382	.491799
21	.358368	-63.0	159	222	1.002004	.708524	.474114
22	.374607	-60.1	158	218	.982438	.694688	.456865
23	.390731	-57.3	157	214	.962907	.680878	.440040
24	.406737	-54.5	156	210	.943418	.667097	.423630
25	.422618	-51.8	155	207	.923972	.653347	.407624
26	.438371	-49.1	154	203	.904576	.639632	.392015
27	.453990	-46.4	153	199	.885232	.625954	.376794
28	.469472	-43.8	152	196	.865945	.612316	.361955
29	.484810	-41.2	151	192	.846719	.598721	.347489
30	.500000	-38.7	150	189	.827559	.585172	.333392
31	.515038	-36.2	149	185	.808467	.571673	.319657
32	.529919	-33.7	148	182	.789450	.558225	.306279
33	.544639	-31.2	147	178	.770510	.544833	.293252
34	.559193	-28.8	146	175	.751653	.531499	.280571
35	.573576	-26.3	145	171	.732882	.518226	.268231
36	.587785	-23.9	144	168	.714202	.505017	.256229
37	.601815	-21.6	143	165	.695618	.491876	.244560
38	.615661	-19.2	142	161	.677132	.478805	.233218
39	.629320	-16.9	141	158	.658751	.465807	.222202
40	.642788	-14.6	140	155	.640479	.452887	.211505
41	.656059	-12.3	139	151	.622319	.440046	.201125
42	.669131	-10.0	138	148	.604277	.427288	.191058
43	.681998	-7.7	137	145	.586357	.414617	.181301
44	.694658	-5.4	136	141	.568564	.402035	.171848
45	.707107	-3.2	135	138	.550902	.389546	.162698
46	.719340	-1.0	134	135	.533376	.377154	.153845
47	.731354	1.2	133	132	.515991	.364861	.145288
48	.743145	3.5	132	129	.498752	.352671	.137022
49	.754710	5.6	131	125	.481664	.340588	.129044
50	.766044	7.8	130	122	.464732	.328615	.121349
51	.777146	10.0	129	119	.447960	.316755	.113936
52	.788011	12.2	128	116	.431354	.305013	.106800
53	.798636	14.3	127	113	.414919	.293392	.099938
54	.809017	16.4	126	110	.398660	.281895	.093346
55	.819152	18.6	125	106	.382583	.270527	.087021
56	.829038	20.7	124	103	.366694	.259292	.080959
57	.838671	22.8	123	100	.350997	.248192	.075156
58	.848048	24.9	122	97	.335499	.237234	.069609
59	.857167	27.0	121	94	.320206	.226420	.064314
60	.866025	29.1	120	91	.305123	.215755	.059267
61	.874620	31.2	119	88	.290258	.205243	.054464
62	.882948	33.3	118	85	.275616	.194890	.049902
63	.891007	35.4	117	82	.261203	.184699	.045576
64	.898794	37.4	116	79	.247028	.174675	.041482
65	.906308	39.5	115	75	.233096	.164824	.037616
66	.913545	41.6	114	72	.219416	.155150	.033974
67	.920505	43.6	113	69	.205994	.145660	.030551
68	.927184	45.7	112	66	.192840	.136358	.027344
69	.933580	47.7	111	63	.179960	.127251	.024346
70	.939693	49.7	110	60	.167365	.118345	.021555
71	.945519	51.8	109	57	.155063	.109646	.018964
72	.951057	53.8	108	54	.143065	.101162	.016569
73	.956305	55.8	107	51	.131380	.092900	.014365
74	.961262	57.9	106	48	.120020	.084867	.012347
75	.965926	59.9	105	45	.108998	.077073	.010509
76	.970296	61.9	104	42	.098325	.069526	.008845
77	.974370	63.9	103	39	.088017	.062237	.007350
78	.978148	65.9	102	36	.078089	.055217	.006018
79	.981627	68.0	101	33	.068558	.048478	.004842
80	.984808	70.0	100	30	.059444	.042033	.003816
81	.987688	72.0	99	27	.050769	.035899	.002933
82	.990268	74.0	98	24	.042558	.030093	.002185
83	.992546	76.0	97	21	.034841	.024636	.001565
84	.994522	78.0	96	18	.027654	.019554	.001064
85	.996195	80.0	95	15	.021041	.014878	.000675
86	.997564	82.0	94	12	.015058	.010647	.000386
87	.998630	84.0	93	9	.009781	.006916	.000188
88	.999391	86.0	92	6	.005325	.003765	.000068
89	.999848	88.0	91	3	.001883	.001331	.000012
90	1.000000	90.0	90	0	0.000000	0.000000	0.000000

Crest R.F Volts = 44 KV

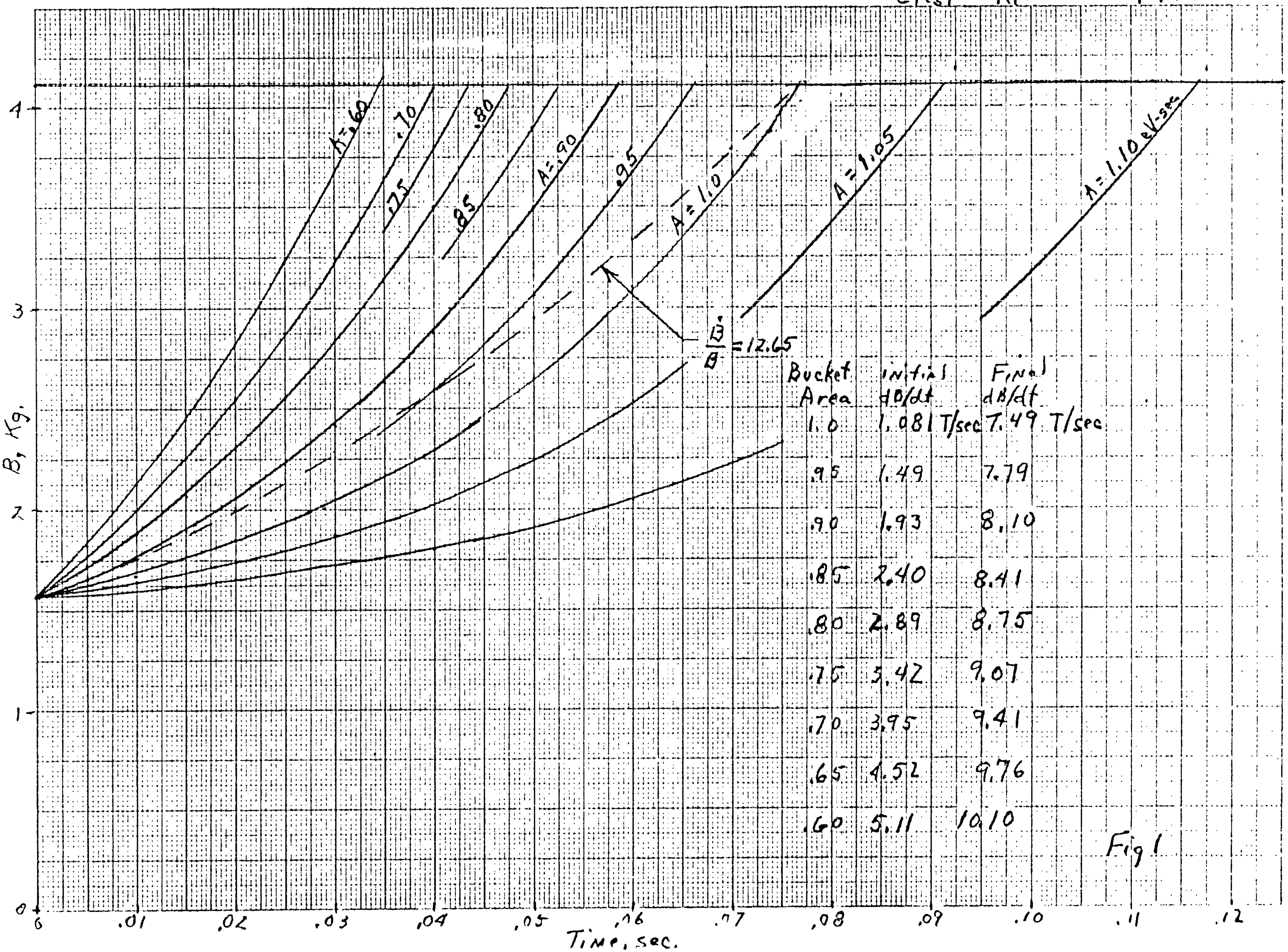

Fig 1

Crest R.F. Volts = 48 KV

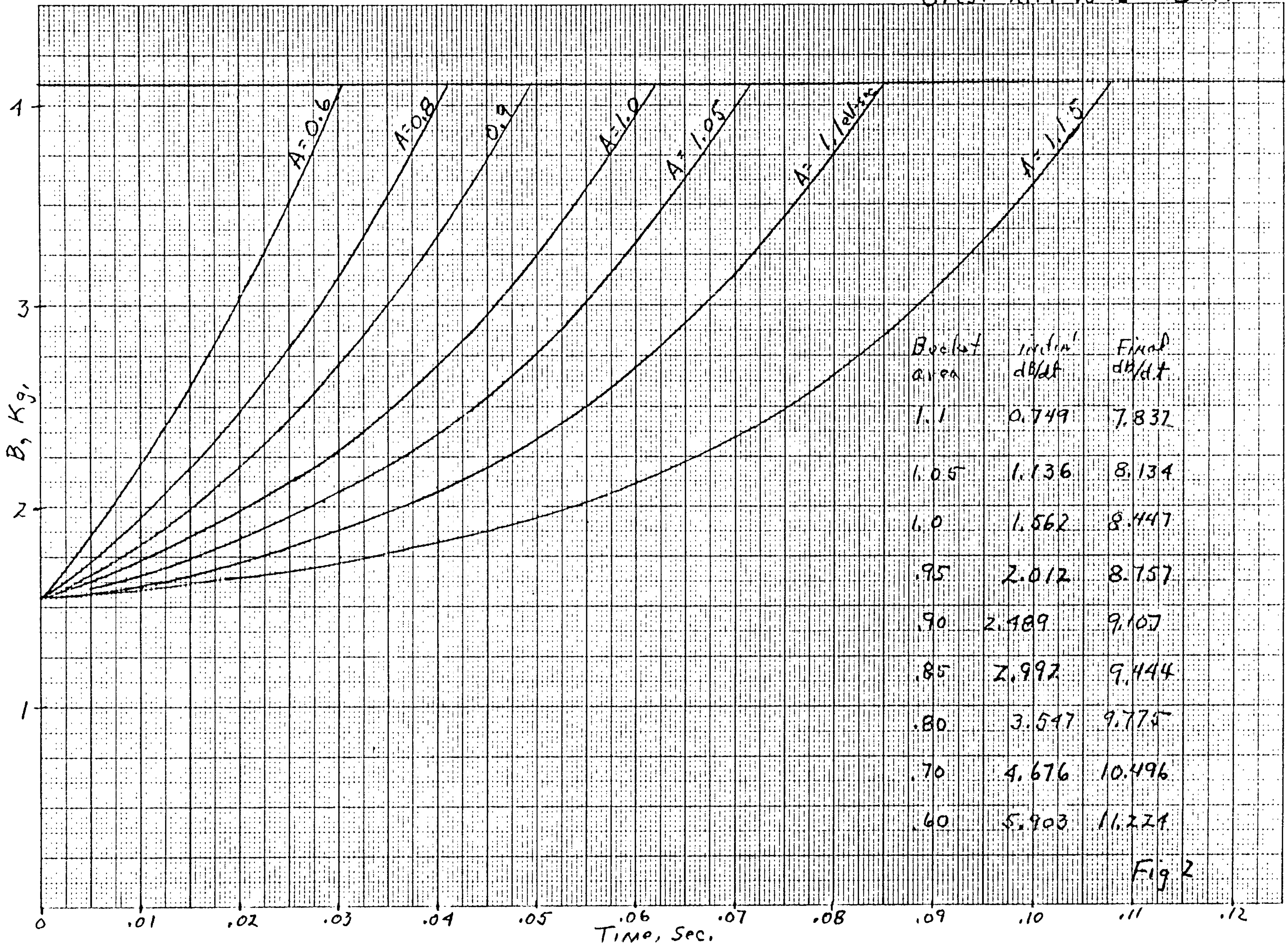

Fig 2