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Consideration effecting the booster magnet cycle

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Collider Accelerator Department

Brookhaven National Laboratory

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Booster Tech. Note

CONSIDERATION EFFECTING THE BOOSTER MAGNET CYCLE

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In order to study the booster magnet cycle I have assumed the following set of parameters. (Caution -- these parameters have not been circulated and may not represent the latest information.)

Number of magnets	36
Inductance per magnet	.049 hen.
Total independence	.176 hen.
Injection field	.1557 tesla
Injection current	640 amps.
1 Gev current	1690 amps.
Magnet resistance, total	0.09 ohms

There are four processes that consume a fixed quantity of time which must be removed from the basic repetition period. These processes are as follows.

Transion from Rectify to Invert

When the rectifier timing is shifted from rectify to invert the rectifier output follows the last rectify sine wave down to the point of the first invert commutation. This elapse time is less than a full half sine wave time because the invert process must be triggered ahead of the voltage cross-over point (see Fig. 1). Before the voltage cross-over is reached two things must happen: 1) the extinguishing rectifier must have recovered its voltage hold-off ability. This time is specified by the manufacturer for the SCR rectifier used and is typically 400 microseconds for rectifiers of this class although "fast recovery" units are available at a premium price. 2) Sufficient time must be allowed for the current to commutate from one rectifier to the next. This current transfer time is a function of the transformer commutating reactance and the potential difference between the commutating phases. To estimate the commutation time I have assumed a transformer reactance of 6% which is about the lower limit for rectifiers transformers of this class. Under this assumption the commutation time is 32.2 degrees or .0015 sec. (Note -- the time required for this process is already slightly greater than the phase spacing for a 12 phase rectifier, 30 degrees. For this reason going to a rectifier with more phases does not reduce the raw ripple voltage.) The sketch shown in the top of Fig. 1 illustrates this process. The time between rectifier firings during this changeover process is 139.2 degrees or 6.4 millisec.

Filter Recovery

The dipole rectifier system must contain a ripple filter with a minimum attenuation at the fundamental ripple frequency of 10. I would prefer an attenuation of 30 to give some margin against excess (unexpected) raw ripple, but in the interest of minimizing the time lost to the filter recovery process I have cut the filter requirements in this analysis to a minimum.

Both filter designs are shown in Fig. 2. Filter "A" has an attenuation of 30 while filter "B" has only the minimum 10 required. The response of these filters to a step input is also shown. The recovery time using filter "B" is about 6 millisec.

Regulator Recovery

If we require that each pulse be independent of any preceeding pulse then the magnet current must be under regulation prior to injection, thus correcting any variation caused by the preceeding pulse. A time interval is required for this correction. The primary disturbance that must be corrected by this regulation process is variations in line voltage. Brookhaven operates with a 5/8% line voltage tap changer and I suggest that we plan to correct for two of these steps or 1.25%. If injection needs current control to 0.05% then a regulator correction of 25 is required. This takes 3.2 correction intervals, if each interval reduces the error by e. The correction interval is limited by the response of the filter and the commutation time of the rectifier. These times are respectively 1.7 and 1.3 millisec for a total correction interval of 3.0 millisec. Thus the correction time becomes about 10 millisec. (Note -- we have pushed this time down near the theoretical limit. I don't believe it can be reduced any further.)

Injection Under Shoot

During the filter recovery and while the regulator is correcting for errors produced by the preceeding pulse the injection magnet voltage must be applied to the magnet. Magnet current is, therefore, rising during this time interval, and must have started from a current below the desired injection value. The invert ramp must have carried the current to this reduced value and about 6 millisec of time is needed for this action.

Once a repetition period is assigned and these "dead" times are substracted the remaining time can be proportioned between the rectify and invert parts of the cycle. The current in the invert part of the cycle can ramped downward limited only by power supply capability. But the rising current in the rectify part of the cycle must be controlled to preserve the r.f.

bucked area. I have used an approximation of this constant r.f. bucked area process namely holding the ratio of $\dot{B}/B$ constant in computing the examples shown in Tables I through III. These tables contain the cycle parameters for three assumed repetition periods, .100, .1167 and .1333 sec. The data in Table I assumes that the rectifier is sized to produce the maximum rise rate required and no additional voltage capability exists. Table II assumes that the rectifier has in additional 25% over voltage capability and this is used in the invert process. Table III assumes a 50% over voltage capability.

Table I

Rep. period, sec.	.100	.1167	.1333
K exponent coef, sec.$^{-1}$	23.32	18.98	16.01
Injection, turnaround, sec.	.022	.022	.022
Invert roll-over, sec.	.005	.005	.005
Rect period, sec.	.0416	.0512	.0606
Invert period, sec.	.0313	.0385	.0456
di/dt, inj	$1.49\text{x}10^4$	$1.21\text{x}10^4$	$1.02\text{x}10^4$
di/dt, 1 Mev, A/sec	$3.94\text{x}10^4$	$3.21\text{x}10^4$	$2.71\text{x}10^4$
dB/dt, inj, T/sec	3.62	2.94	2.48
E_{max} rect, (L=.176h) volts	6934	5650	4770
Peak power, MW	11.72	9.55	8.06
Peak power swing, MW	21.68	17.67	14.91
dB/dt, 1Mev, T/sec.	9.57	7.79	6.57

Table II

25% more invert voltage

Rep. period sec.	.100	.1167	.1333
Rect time, sec.	.0456	.056	.0663
Invert time, sec.	.0274	.0337	.0400
K, exponent coef	21.32	17.35	14.63
di/dt, inj, A/sec	$1.36\text{x}10^4$	$1.11\text{x}10^4$	0.94
dB/dt, inj, T/sec	3.32	2.70	2.28
di/dt, 1Mev, A/sec.	$3.60\text{x}10^4$	$2.93\text{x}10^4$	$2.47\text{x}10^4$
E_{max}, rect, V	6341	5160	4351
E, invert, V	6738	5483	4623
Power swing, MW	22.1	17.99	15.16
dB/dt, 1Mev, T/sec.	8.76	7.13	6.01

Table III

50% more invert voltage

Rep. period, sec.	.100	.1167	.1333
K exponent coef	19.98	16.26	13.72
Rect time, sec.	.0486	.0597	.0708
Invert time, sec.	.0244	.0300	.0355
di/dt, inj, A/sec.	1.28×10^{4}	1.04×10^{4}	0.88×10^{4}
dB/dt, inj, T/sec.	3.11	2.53	2.14
di/dt I_{max}, A/sec.	3.38×10^{4}	2.71×10^{4}	2.32×10^{4}
E_{max} rect (L .176h), V	5943	4777	4081
E_{max} invert, V	7577	6090	5203
Power swing, MW	22.8	18.4	15.69
db/dt, 1Mev, T/sec.	8.22	6.59	5.64

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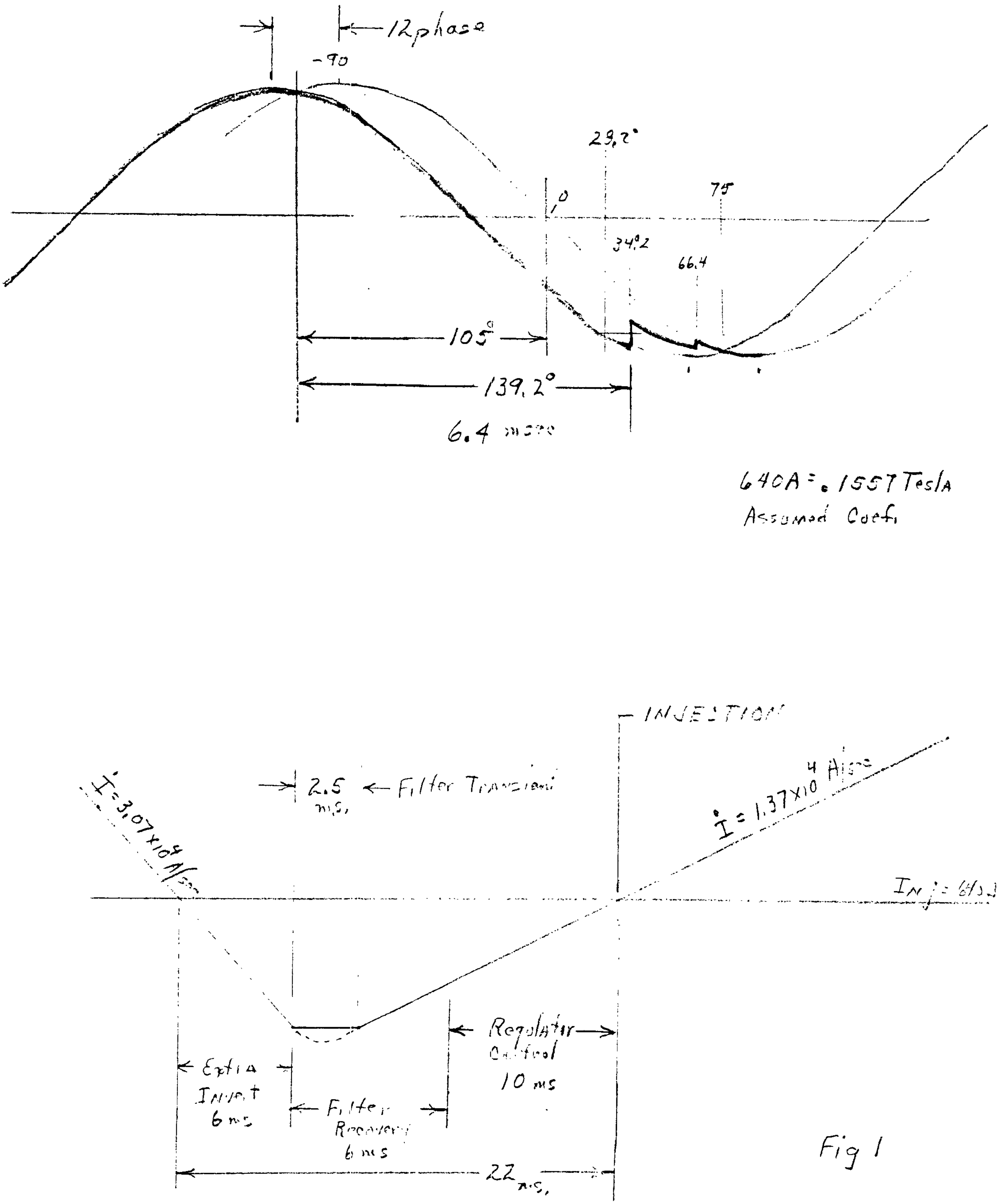
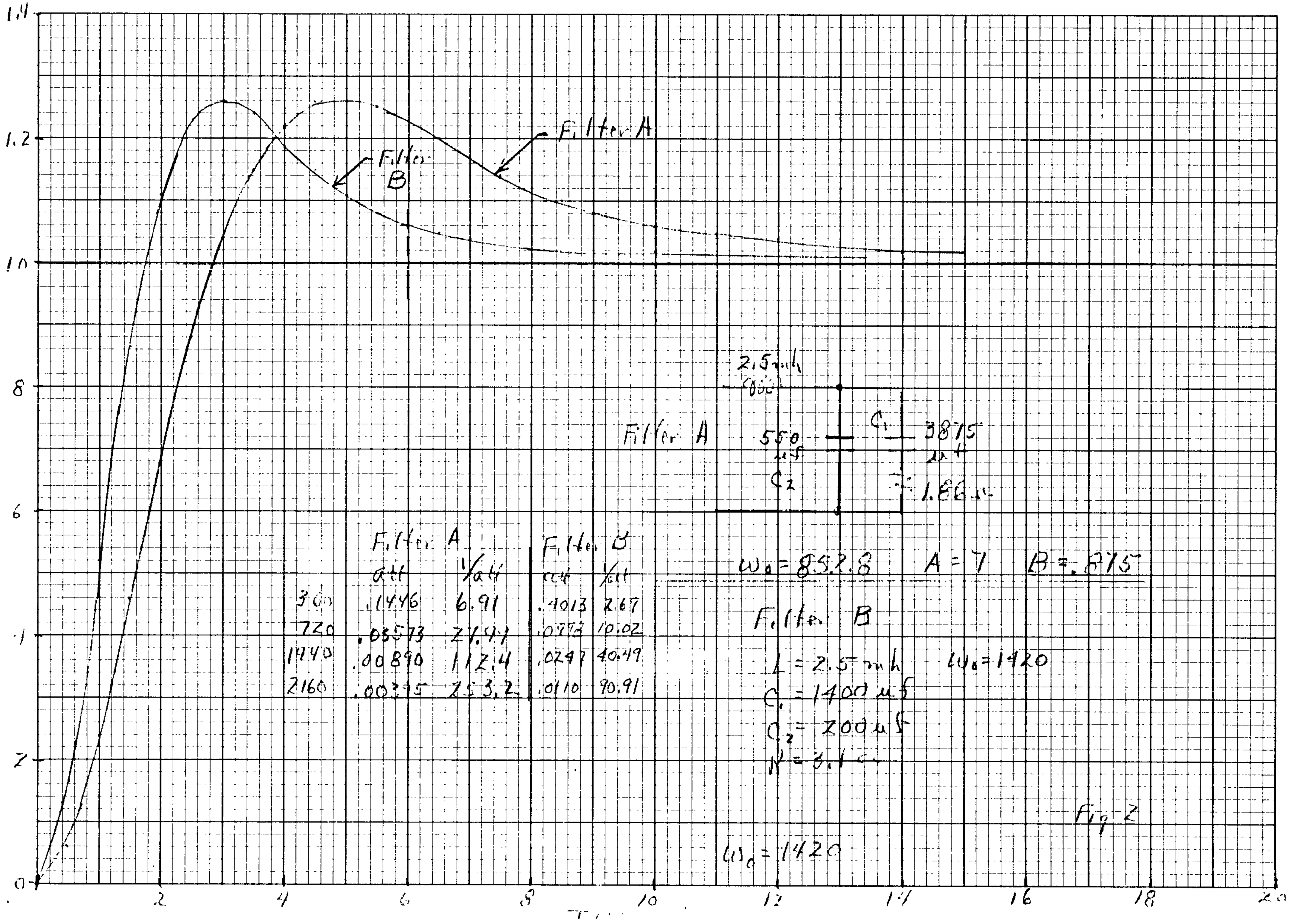


Fig 1

4802



	Filter A att	Filter A 1/att	Filter B att	Filter B 1/att
360	.1446	6.91	.4013	2.67
720	.03573	27.97	.0998	10.02
1440	.00890	112.4	.0247	40.49
2160	.00395	253.2	.0110	90.91