MI-0027A

150 GEV AND REVISED 120 GEV RAMPS

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MI Note 0027A
150 GeV and Revised 120 GeV Ramps

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This note describes the 150 GeV ramp for the Main Injector, and revised calculations of the 120 GeV ramp. The change in the 120 GeV ramp is a reduction of the estimate of the ring resistance from 400 mΩ to 320 mΩ. The ramp and rf waveforms have not changed. There are a number of considerations which make the 150 GeV ramp different from the 120 GeV ramp at high field. The low field properties, i.e. ramp rate and rf voltages, are the same as the 120 GeV ramp, except for 8 GeV dwell time. The ramp given below is appropriate for fixed target injection into the Tevatron; the collider injection ramp will need a longer flattop, and will have to be restricted in its repetition rate. The ramp shown is intended to be run twice in succession, once a minute, with 120 GeV cycles the remainder of the time. The transformers for the Main Injector are being sized for a current (average between peak and rms) of 6500 A; if this ramp is to be run repetitively, the repetition rate must be slowed to reduce the rms current to ~3600 A (~5.4 sec rep rate). The 120 GeV slow spill ramp is also given.

There are 150 GeV files on Page M3, under **$2D** resets. The 120 GeV files have been moved to the $2D resets also. There are also 150 GeV files on D126. Copies of the waveforms are attached. Please inform me if you discover problems with any of these waveforms, so that I can correct them and issue an update. The 120 GeV slow spill flattop allows for 1 second of slow spill. Any time required for rf manipulations for producing a satisfactory beam distribution will reduce the available spill time. Mixed mode of antiproton production plus slow spill will require an additional .1-.2 sec. (See MI Note 40 for comments regarding extraction at F17.) The observent reader will note that there is in fact an extra 15 Hz increment at the end of the ramp. Elimination of this increment would reduce the cycle time to 2.80 sec, while increasing the power and rms currents.

150 GeV Ramp description

The input to the calculations of power supply voltage are: 9417 A = 150 GeV/c; L = 613 mH; R = 320 mΩ. While this is the "proper" value for 150 GeV, saturation is not taken into account. Approximately 12000 V is the maximum available during convert, slightly less during invert. The resistance is comprised of 254 mΩ from the magnets, with the remainder coming from bus work, filters, etc. There is still some uncertainty in this number, and an extra 11 mΩ has been added to err on the conservative side.

The ramp begins with a .441 sec injection level, (.108 sec, as for the 120 GeV, single batch ramp, plus .333 seconds for five additional batches). Feeder current limitations force the ramp rate to fall off above 120 GeV. The result of this restriction is that as one approaches the parabola coming into flattop, no more than nine power supplies can be turned on. Ramp regulation which puts supplies into bypass is required. **While this improves the feeder currents, it raises the peak voltage to ground and bus to bus voltage that the magnets experience.**

Invert has been adjusted in a similar manner. Flattop is 250 msec long, which should be adequate for phase locking to the Tevatron and cogging by a maximum of 10 buckets, the difference in revolution times being used to provide the remainder of the cogging. The undershoot and subsequent dwell time are the same as the 120 GeV ramp. The total time is 2.4 sec, or 36 15-Hz cycles.

Rf Voltage

The rf voltage curve is roughly the same as for the 120 GeV ramp. At high field, the rf voltage is limited to 534 kV to match the 1.2 MV in the Tevatron; for Collider operation, these levels are reduced to 356 kV and 800 kV, respectively.

Power Supply Control

The power supplies are assumed to be controlled differently on different cycles. For the fast cycling 120 GeV cycle (with very short flattop) one power supply is used at 8 GeV, but as the ramp begins, the remaining power supplies are turned on simultaneously. For the 150 GeV cycle, the supplies are turned on and off as required by voltage demands, with either 1, 4, 8, 10 or 12 supplies on at once. For the 120 GeV slow spill cycle, 1, 3 or 12 supplies are energized. This sequential turn-on is required to minimize voltage to ground distributions and rms feeder currents.

The attached pages detail the ramp waveform, rf waveform, beam properties and power calculations. The table below summarizes some of the relevant properties and power requirements for each of the ramps.

Ramp	150 GeV	120 GeV (Fast)	120 GeV (Slow Spill)	
DIPOLE BUS				
Cycle Time	2.4	1.4667	2.8667	sec
Max. Current	9417	7100	7100	A
RMS Current	5434	3765	4988	A
Power	9.4	4.5	8.0	MW
RMS Feeder Current	1991	2054	1473	A
Peak Feeder Volt-Amps	98	94	94	MVA
Average Feeder Volt-Amps	48	49	35	MVA
QUAD BUS (sum of both)				
Max. Current	3630	2904	2904	A
RMS Current	2095	1540	2040	A
Power	4.8	2.5	4.4	MW
RMS Feeder Current	444	316	336	A
Peak Feeder Volt-Amps	21	16	16	MVA
Avearage Feeder Volt-Amps	11	8	8	MVA

Appendix A
Dipole Resistance and Inductance Calculation

Assumptions:

MI Note 0006:
R(dipole) = .848 mΩ; this corresponds to 40°C.
L(Dipole) = 2.003 mH;

Bus resistance corresponding to 4 sq in of copper conductor = 2.13 μΩ/ft @ 40°C.

Power Supplies = 2 mΩ + 1 mH; tunnel to power supplies = 100' one way.

Ring circumference	3319 m		
300 dipoles x 6.096 m	1829 m		
Difference	1491 m		
x 2	2982 m		
Add:			
4 m of bus at each 1/2 cell containing dipoles (164)	656 m		
Total	3638 m		
Convert to feet	12000'	26 mΩ	Tunnel Bus
Add:			
12 x 2 mΩ		24 mΩ	Power Supplies
12 x 200' x 2 μΩ/ft		5 mΩ	Stairwell Bus
Total Non-magnet Resistance		55 mΩ	
Magnet Resistance		254 mΩ	
"Contingency"		11 mΩ	
Total Resistance		320 mΩ	
Inductance:			
300 Magnets x 2.003/dipole		601 mH	
12 P.S. x 1 mH/P.S.		12 mH	
Total		613 mH	

Comment on operating costs: 1 mΩ of resistance ==> $10,000 per year
The bus work (26 + 5 mΩ) comprises 10% of the total resistance.

Appendix B
Quad Resistance and Inductance Calculation

Assumptions:

202 quads - treat as all 84";

TM-424, TM-632:
R(quad) = 4.76 mΩ; (temperature unknown);
L(quad) = 1.3 mH;

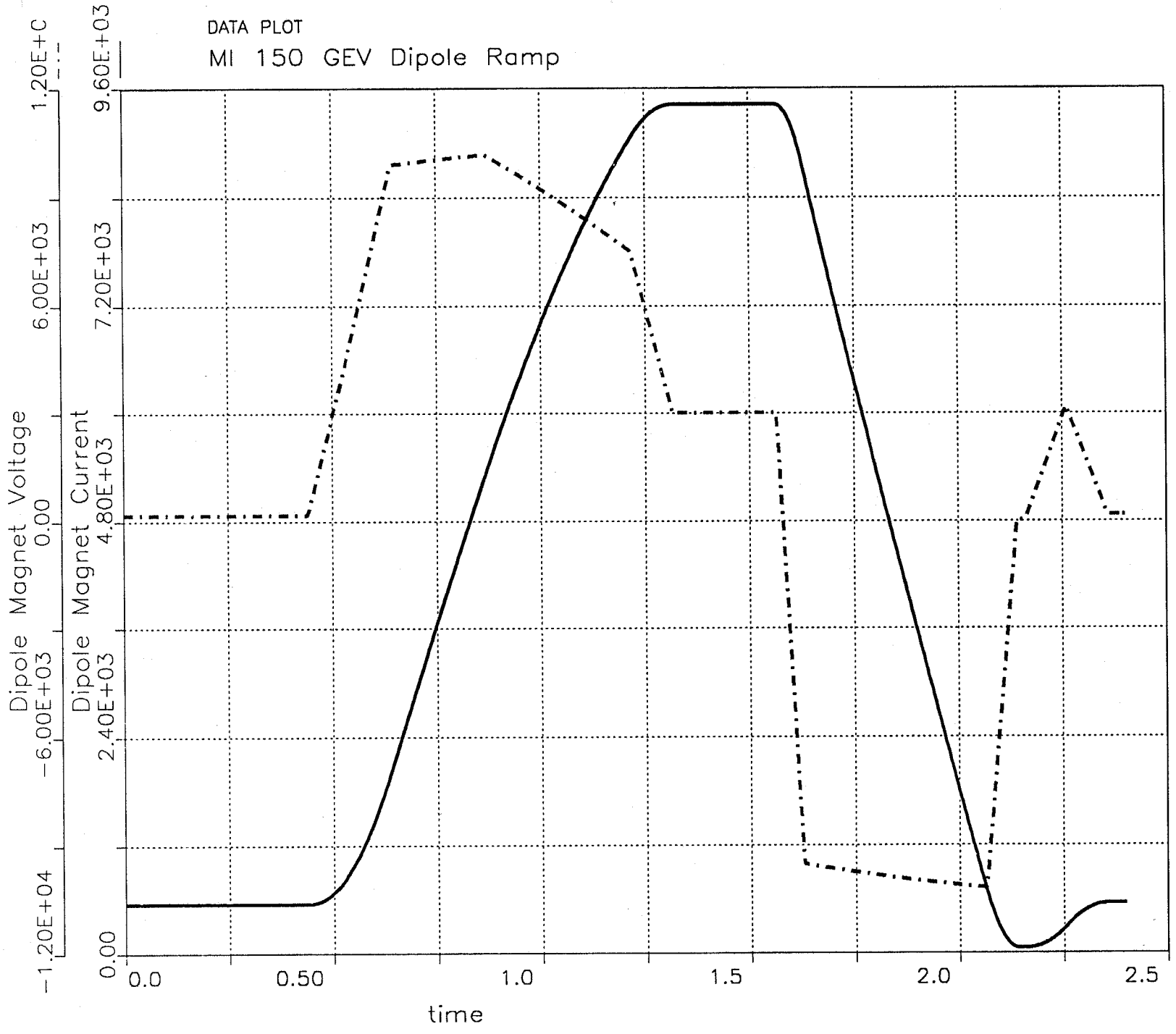
Bus resistance corresponding to 2 sq in of copper conductor = 4.26 μΩ/ft @ 40°C.

Power Supplies = 2 mΩ + 1 mH; tunnel to power supplies = 100' one way.

Ring circumference	3319 m		
x 2	6638 m		
Convert to feet	21800'	93 mΩ	Tunnel Bus
Add:			
6 x 2 mΩ		12 mΩ	Power Supplies
6 x 200' x 4 μΩ/ft		5 mΩ	Stairwell Bus
10' x 202 quads for connections		9 mΩ	
Total Non-magnet Resistance		119 mΩ	
Magnet Resistance		962 mΩ	
Total Resistance (BOTH busses)		1081 mΩ	
Total Resistance PER BUS		540 mΩ	

Inductance:	
202 quads x 1.3 mH/quad	263 mH
6 P.S. x 1 mH/P.S.	6 mH
Total (BOTH busses)	269 mH
Total PER BUS	135 mH

Comment on operating costs: 1 mΩ of resistance ==> $1500 per year
The bus comprises 9.8% of the total resistance.


DATA PLOT
MI 150 GEV Dipole Ramp
Dipole Magnet Voltage
1.20E+04
6.00E+03
0.00
-6.00E+03
-1.20E+04
Dipole Magnet Current
9.60E+03
7.20E+03
4.80E+03
2.40E+03
0.00
0.0
0.50
1.0
1.5
2.0
2.5
time

RAMP POWER CALCULATIONS PROGRAM

MI 150 GeV (DIPOLES)

INPUT DATA :

Ring current/energy ratio (amps/GEV) = 62.780
Total ring inductance (Henry) = 0.61300
Total ring resistance (ohms) = 0.32000
Desired Max. Operating Voltage for Holding PS = 0.100E+04
Desired Max. Operating Voltage for Ramping PSs = 0.100E+04
Number of power supplies = 12
Maximum Voltage Available from Holding PS = 1100.0
Maximum Voltage Available from Ramping PS = 1100.0
Feeder Voltage (line-to-line) = 13800.
The Power Supply Turn-on order:
1 4 8 10 12 12 12 12 12 12 12 12

Number of lines in ramp description = 14
The following are the ramp parameters:

TIME	+MOMENTUM+	***Pdot***	+++Pddot++
0.44100	8.8890	0.00000	0.00000
0.64100	32.889	240.00	1200.0
0.86757	85.000	220.00	-88.273
1.2146	144.00	120.00	-288.14
1.3146	150.00	0.00000	-1200.0
1.5646	150.00	0.00000	0.00000
1.6271	140.00	-320.00	-5120.0
2.0644	11.000	-270.00	114.34
2.1392	0.90000	0.00000	3608.9
2.1592	0.90000	0.00000	0.00000
2.2592	4.9000	80.000	800.00
2.2598	4.9490	80.000	0.00000
2.3583	8.8890	0.00000	-812.18
2.4000	8.8890	0.00000	0.00000

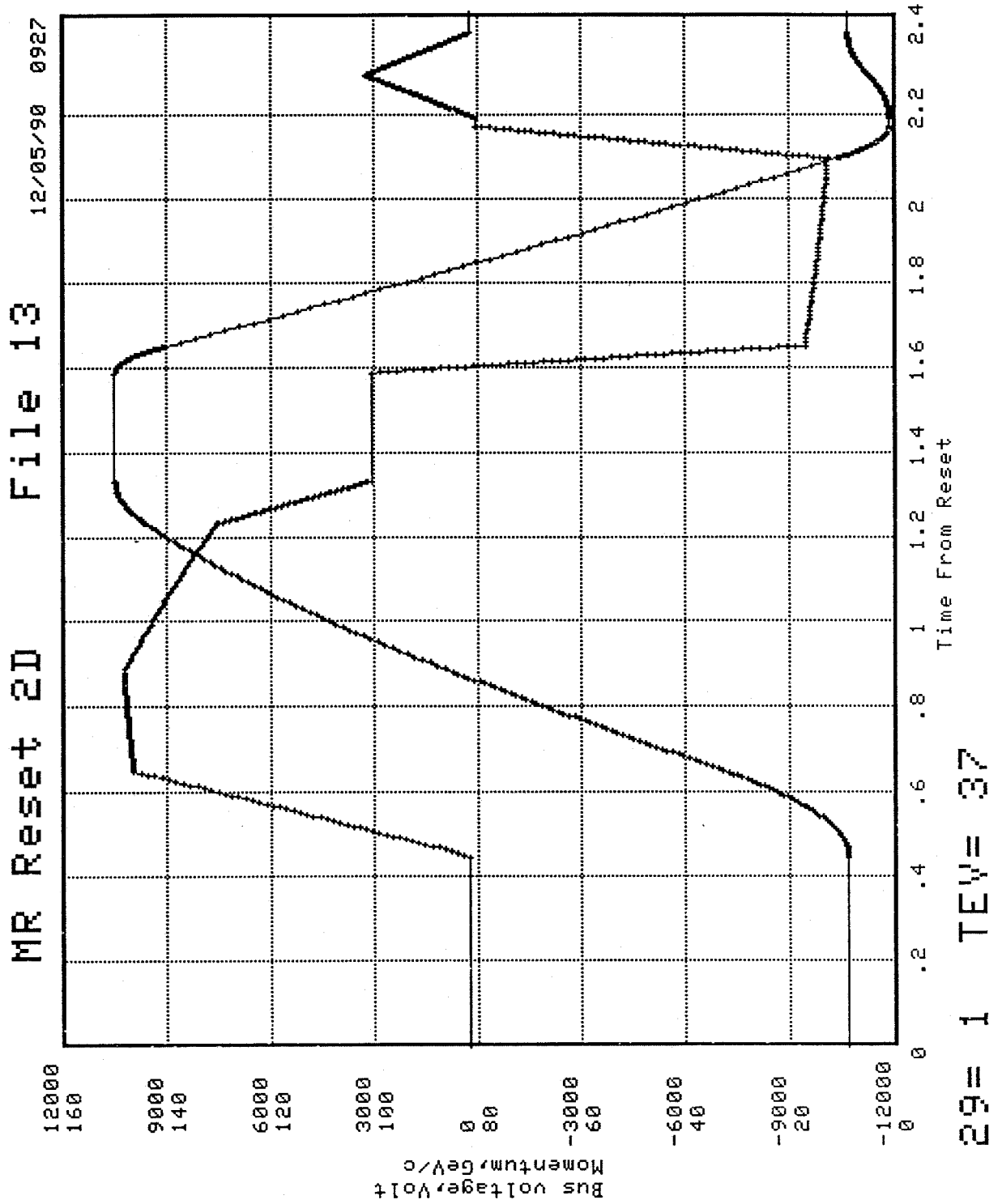
RAMP CALCULATIONS :

Peak ramp current (amps) = 9417.0
Total RMS ramp current (amps) = 5434.4
Min. and max. ramp voltage (volts) = -10170. 10174.
Maximum number of power supplies = 12
Ramp power (watts) = 0.94505E+07

FEEDER CALCULATIONS :

Peak feeder current (amps) = 4108.4
RMS feeder current (amps) = 1991.2
Peak feeder volt-amps (v-a) = 0.98200E+08
Average feeder volt-amps (v-a) = 0.47595E+08

CONSOLE LOCATION 05; MCRLib 5-DEC-1990 09:27
MR Reset 2D File 13



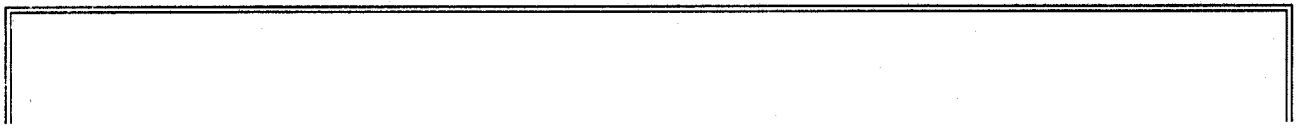
MI - 150 GeV

CONSOLE LOCATION 05; MCRLib 5-DEC-1990 09:27
Main color TV

M3.06 MODIFYing file 13 MAIN INJ 150 GEV RAMP-DO NOT LOAD!!!!!
*file dir *ch-rf *ch-plot *ch-const *CH-RAMP *ch-chrom *ch-rag
RESET(2D) *calc *delete *insert

----------values at end of sequence----------

SEQ	TYPE	Dt	TIME	MOMENTUM	Pdot	Pddot	
01	INITI >	.441	.441	> 8.889	0	0	V-trans = 0
02	VPARAB	0	.441	8.889	0	0	T-trans = .57157
03	PARAB	.2	.641	> 32.889>	240	1200	P-trans = 19.118
04	PARAB	.22657	.86757>	85	> 220	-88.273	
05	PARAB	.34706	1.2146>	144	> 120	-288.14	
06	PARAB	.1	1.3146>	150	> 0	-1200	
07	CAPDEP>	.25	1.5646	150	0	0	
08	PARAB	.0625	1.6271>	140	>-320	-5120	
09	PARAB	.43729	2.0644>	11	>-270	114.34	
10	PARAB	.07481	2.1392>	.9	> 0	3608.9	T22 = .441
11	CAPDEP>	.02	2.1592	.9	0	0	T25 = 1.3146
12	PARAB	.1	2.2592>	4.9	> 80	800	T26 = 1.5646
13	PARAB	.00061	2.2598>	4.949	> 80	0	
14	PARAB	.0985	2.3583>	8.889	> 0	-812.18	
15	CAPDEP>	.0417	2.4	8.889	0	0	



CONSOLE LOCATION 05; MCRLib 5-DEC-1990 09:27
Main color TV

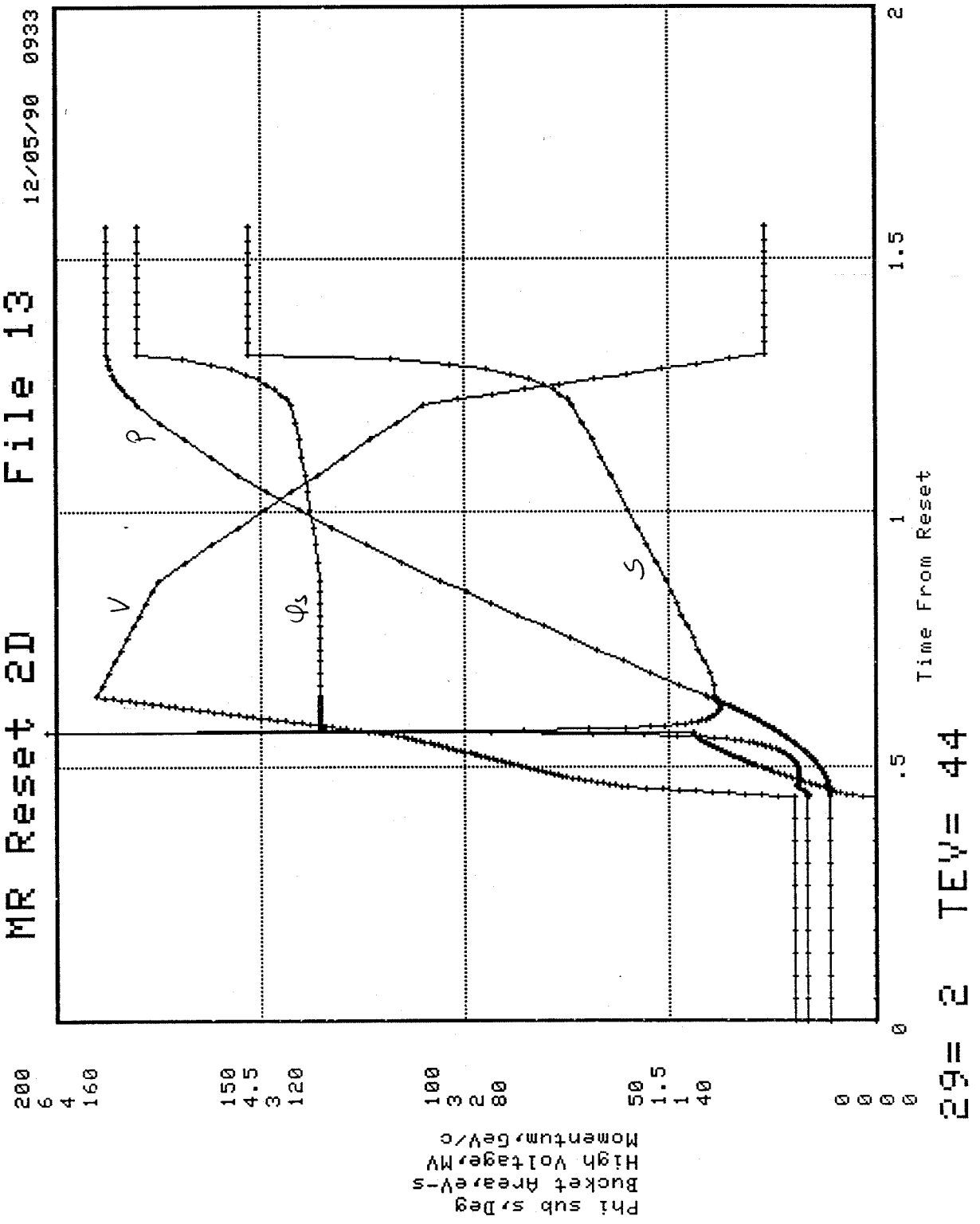
MI 150 GeV

M3.05 Change Constants
*return
RESET(2D)

Max ramp slew rate (GeV/c/sec)	250	
Bend resistance (V/ GeV/c) ...	20.089599	= .32 Ω
Quad resistance (V/ GeV/c) ...	9.7500002	
Bend inductance (V-sec/ Gev/c)	38.484138	= .613 H
Quad inductance (V-sec/ Gev/c)	2.5999999	
Glitch start momentum (GeV/c)	8.8999998	
Glitch stop momentum (GeV/c)	50	
Glitch amplitude (V)	439.99999	
Max glitch slew rate (V/s) ...	15	
Bend current (Amp) / P (GeV/c)	62.779998	⇒ 9417 A = 150 GeV
Voltage curvature (V/s-2)	400000	
VPARAB length (sec)	0	
Bend voltage offset (<+-100V).	81.999999	

CONSOLE LOCATION 05; MCRLib 5-DEC-1990 09:33
MR Reset 2D File 13

MI 150 GeV



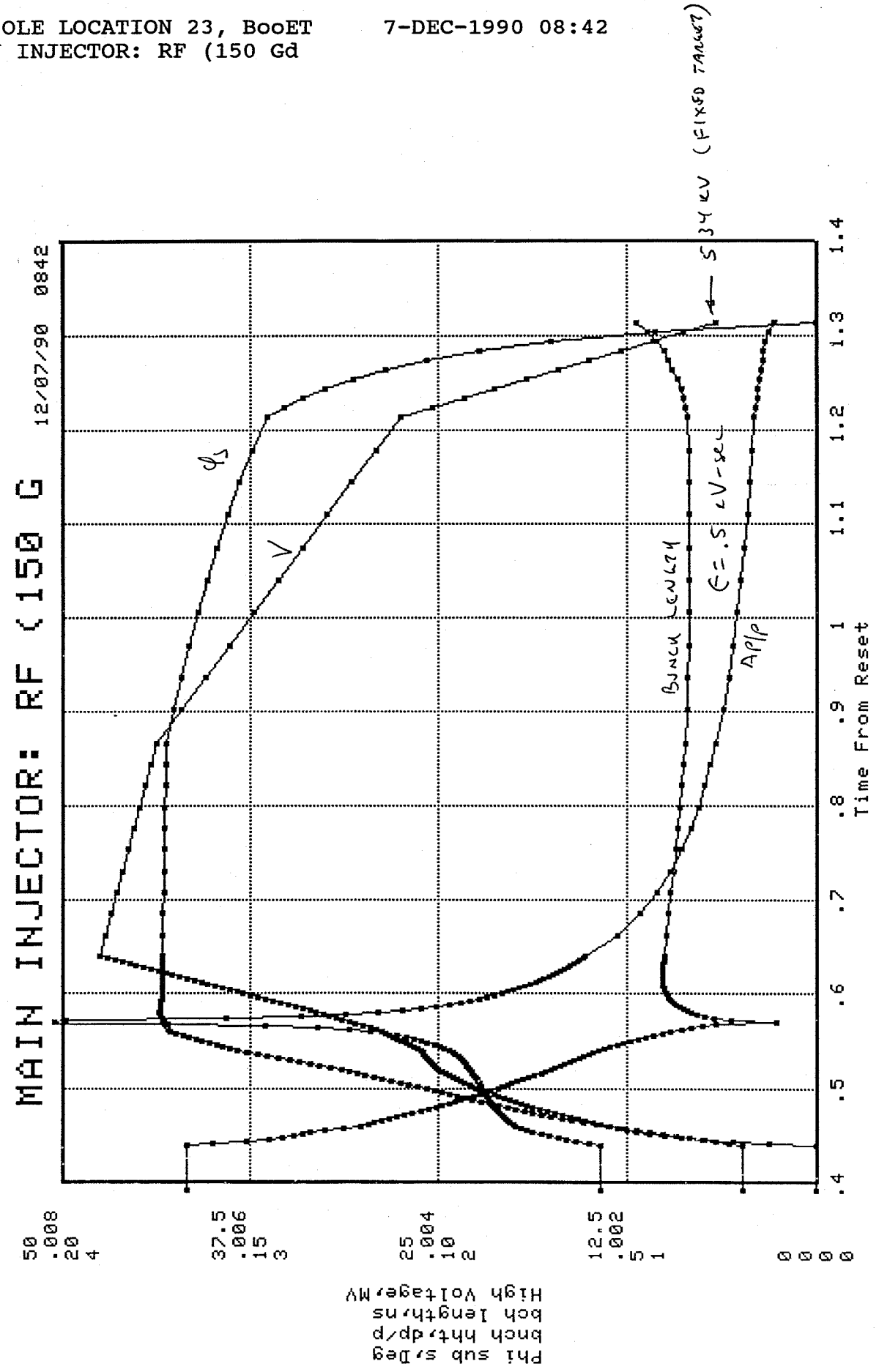
CONSOLE LOCATION 36; MCRLib 6-DEC-1990 08:37
PA:M3 RAMP/LLRF ADJUST

M3.03 MODIFY file 13 MAIN INJ 150 GEV RAMP-DO NOT LOAD!!!!!
*file dir *CH-RF *ch-plot *ch-const *ch-ramp *ch-chrom *ch-rag
RESET(2D) *calc *delete *insert

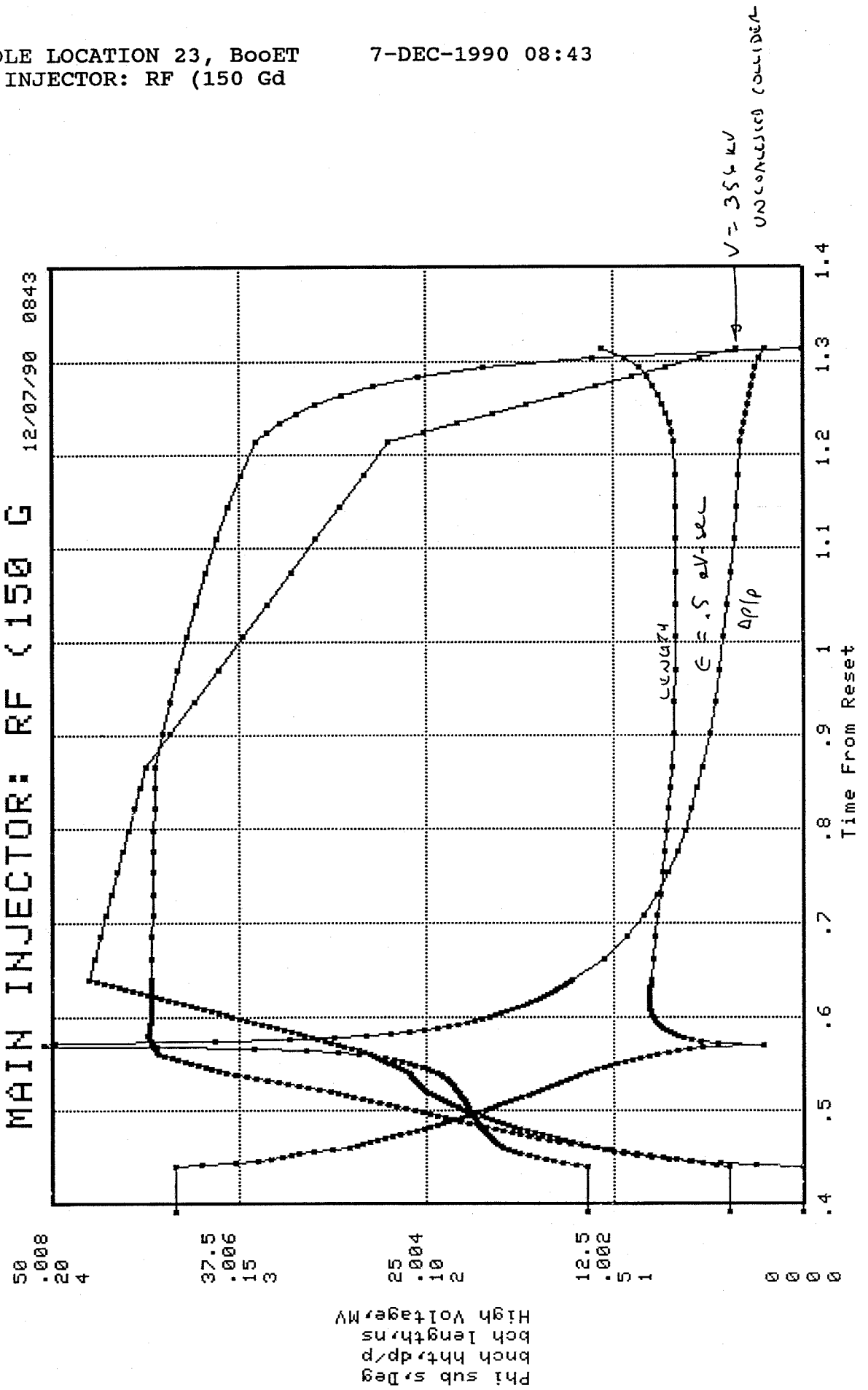
----------values at end of sequence----------

SEQ	TYPE	Dt	TIME	P	Pdot	%dP/P	PHI	HV18	AREA	%HITE
01	Initi>	.001	.001	8.889	0	0	0	>.393	.504	.236
02	Tramp>	.44	.441	8.889	0	0	0	>.393	.504	.236
03	Pramp	.02	.461	>9.129	24	0	13	>1.2	.584	.347
04	Pramp	.02	.481	>9.849	48	0	21	>1.5	.567	.357
05	Pramp	.02	.501	>11.049	72	0	28	>1.7	.568	.363
06	Pramp	.02	.521	>12.729	96	0	34	>1.9	.626	.39
07	Pramp	.02	.541	>14.889	120	0	39	>2.1	.774	.46
08	Pramp	.02	.561	>17.529	144	0	44	>2.3	1.28	.714
09	Pramp	.02	.581	>20.649	168	0	45	>2.65	1.65	.795
10	Pramp	.02	.601	>24.249	192	0	44	>3.04	1.19	.486
11	Pramp	.02	.621	>28.329	216	0	44	>3.42	1.14	.397
12	Pramp	.02	.641	>32.889	240	0	44	>3.8	1.17	.352
13	Pramp	.22657	.86757	>85	220	0	44	>3.5	1.53	.177
14	Pramp	.34706	1.2146	>144	120	0	37	>2.2	2.21	.13
15	Pramp	.1	1.3146	>150	0	0	0	>.534	4.59	.128
16	Tramp>	.25	1.5646	150	0	0	0	>.534	4.59	.128

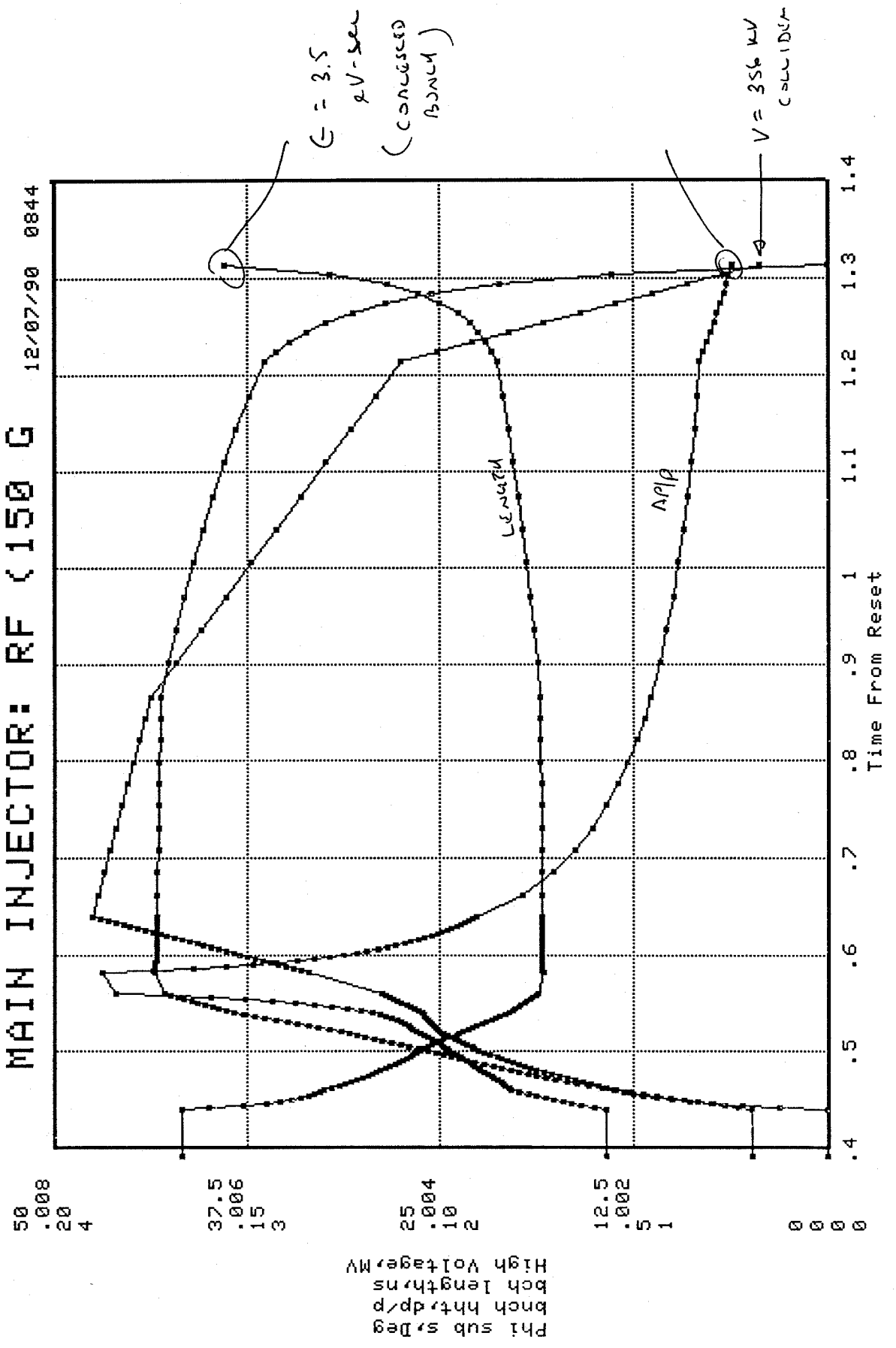
CONSOLE LOCATION 23, BooET 7-DEC-1990 08:42
MAIN INJECTOR: RF (150 Gd

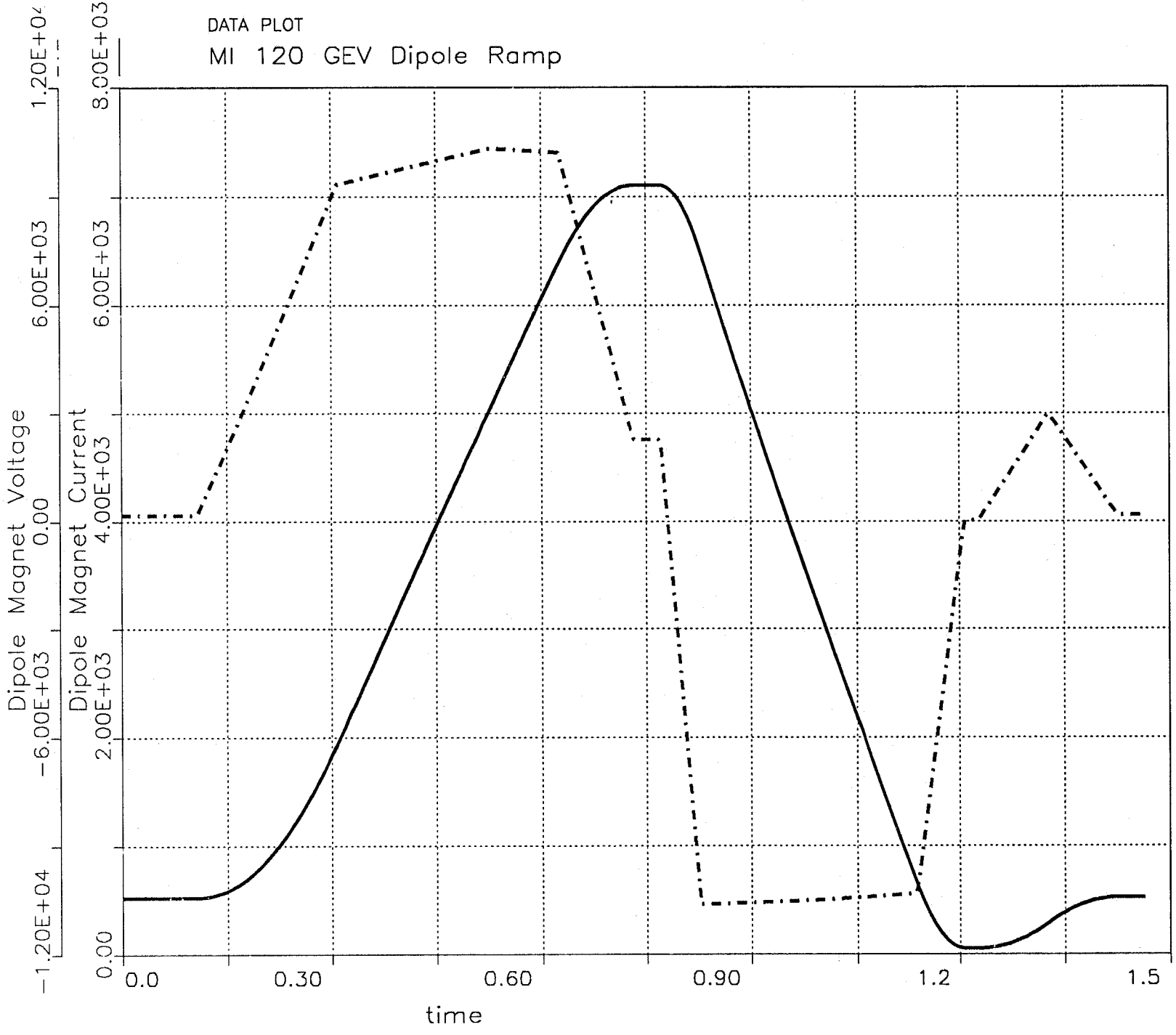


CONSOLE LOCATION 23, BooET 7-DEC-1990 08:43
MAIN INJECTOR: RF (150 Gd



CONSOLE LOCATION 23, BooET 7-DEC-1990 08:44
MAIN INJECTOR: RF (150 Gd




DATA PLOT
MI 120 GEV Dipole Ramp
Dipole Magnet Voltage
1.20E+04
6.00E+03
0.00
-6.00E+03
-1.20E+04
Dipole Magnet Current
8.00E+03
6.00E+03
4.00E+03
2.00E+03
0.00
0.0
0.30
0.60
0.90
1.2
1.5
time

RAMP POWER CALCULATIONS PROGRAM

MI 120 GeV FAST (ORPOSE)

INPUT DATA :

Ring current/energy ratio (amps/GEV) = 59.170
Total ring inductance (Henry) = 0.61300
Total ring resistance (ohms) = 0.32000
Desired Max. Operating Voltage for Holding PS = 0.100E+04
Desired Max. Operating Voltage for Ramping PSs = 0.100E+04
Number of power supplies = 12
Maximum Voltage Available from Holding PS = 1100.0
Maximum Voltage Available from Ramping PS = 1100.0
Feeder Voltage (line-to-line) = 13800.
The Power Supply Turn-on order:
1 12 12 12 12 12 12 12 12 12 12 12

Number of lines in ramp description = 14
The following are the ramp parameters:

TIME	+MOMENTUM+	***Pdot*****	+++Pddot++
0.10800	8.8890	0.00000	0.00000
0.30800	32.889	240.00	1200.0
0.52513	85.000	240.00	0.00000
0.62405	108.00	225.00	-151.63
0.73072	120.00	0.00000	-2109.4
0.77072	120.00	0.00000	0.00000
0.82786	110.00	-350.00	-6125.0
1.1372	11.000	-290.00	193.94
1.2069	0.90000	0.00000	4163.4
1.2269	0.90000	0.00000	0.00000
1.3269	4.9000	80.000	800.00
1.3275	4.9490	80.000	0.00000
1.4260	8.8890	0.00000	-812.18
1.4667	8.8890	0.00000	0.00000

RAMP CALCULATIONS :

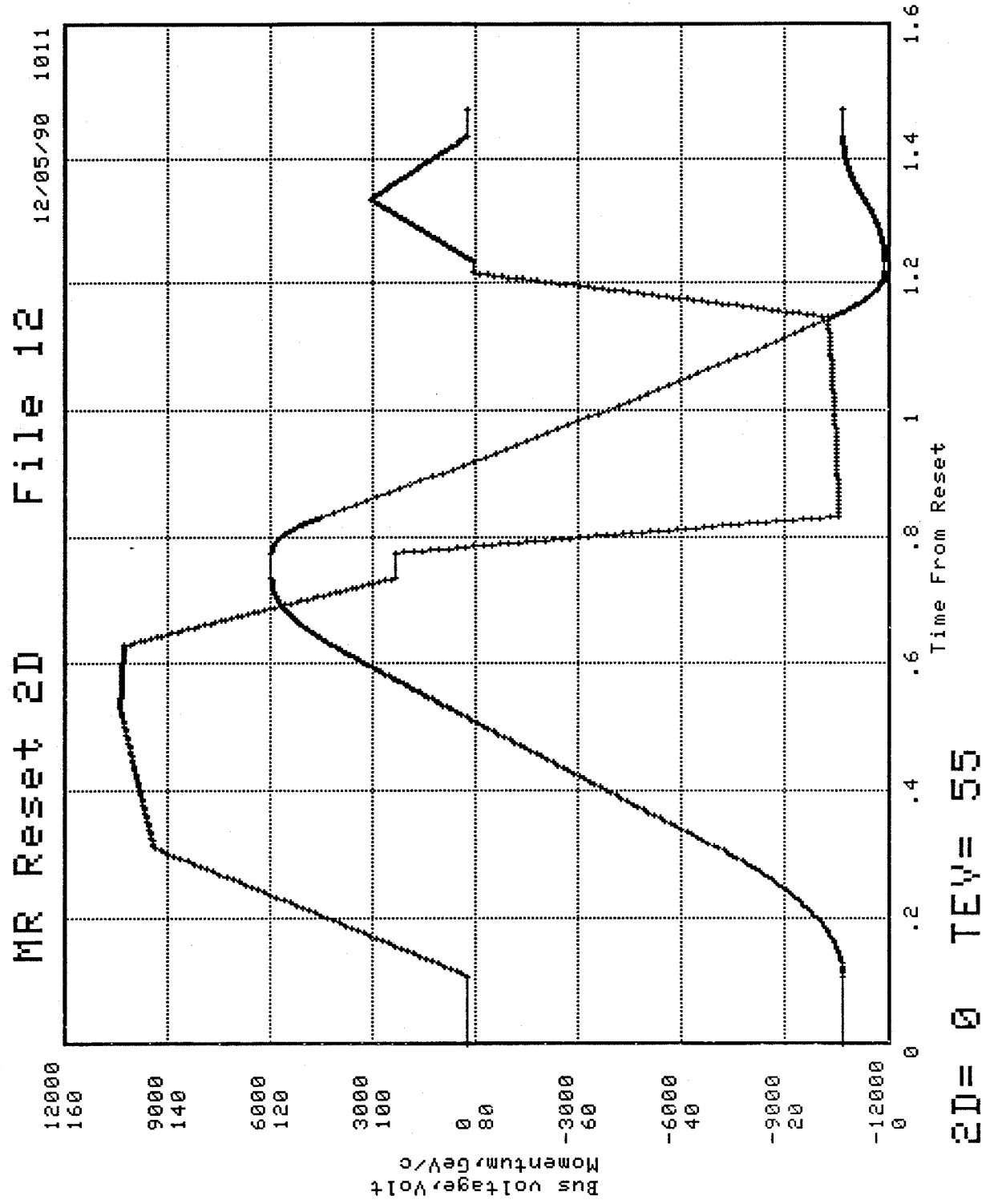
Peak ramp current (amps) = 7100.4
Total RMS ramp current (amps) = 3765.1
Min. and max. ramp voltage (volts) = -10625. 10315.
Maximum number of power supplies = 12
Ramp power (watts) = 0.45363E+07

FEEDER CALCULATIONS :

Peak feeder current (amps) = 3921.2
RMS feeder current (amps) = 2054.0
Peak feeder volt-amps (v-a) = 0.93725E+08
Average feeder volt-amps (v-a) = 0.49095E+08

CONSOLE LOCATION 03; MCR-N2 5-DEC-1990 10:11
MR Reset 2D File 12

MI- 120 GeV Fast



CONSOLE LOCATION 05; MCRLib 5-DEC-1990 09:2
Main color TV

M3.06 MODIFYing file 12 MAIN INJ 120 GEV FAST-DO NOT LOAD!!!!!
*file dir *ch-rf *ch-plot *ch-const *CH-RAMP *ch-chrom *ch-rag
RESET(2D) *calc *delete *insert

----------values at end of sequence----------

SEQ	TYPE	Dt	TIME	MOMENTUM	Pdot	Pddot	
01	INITI >	.108	.108 >	8.889	0	0	V-trans = 0
02	VPARAB	0	.108	8.889	0	0	T-trans = .23857
03	PARAB	.2	.308 >	32.889>	240	1200	P-trans = 19.118
04	PARAB	.21713	.52513>	85 >	240	0	
05	PARAB	.09892	.62405>	108 >	225	-151.63	
06	PARAB	.10667	.73072>	120 >	0	-2109.4	
07	CAPDEP>	.04	.77072	120	0	0	
08	PARAB	.05714	.82786>	110	>-350	-6125	
09	PARAB	.30937	1.1372>	11	>-290	193.94	
10	PARAB	.06966	1.2069>	.9 >	0	4163.4	T22 = .108
11	CAPDEP>	.02	1.2269	.9	0	0	T25 = .73072
12	PARAB	.1	1.3269>	4.9 >	80	800	T26 = .77072
13	PARAB	.00061	1.3275>	4.949 >	80	0	
14	PARAB	.0985	1.426 >	8.889 >	0	-812.18	
15	CAPDEP>	.04	1.466	8.889	0	0	

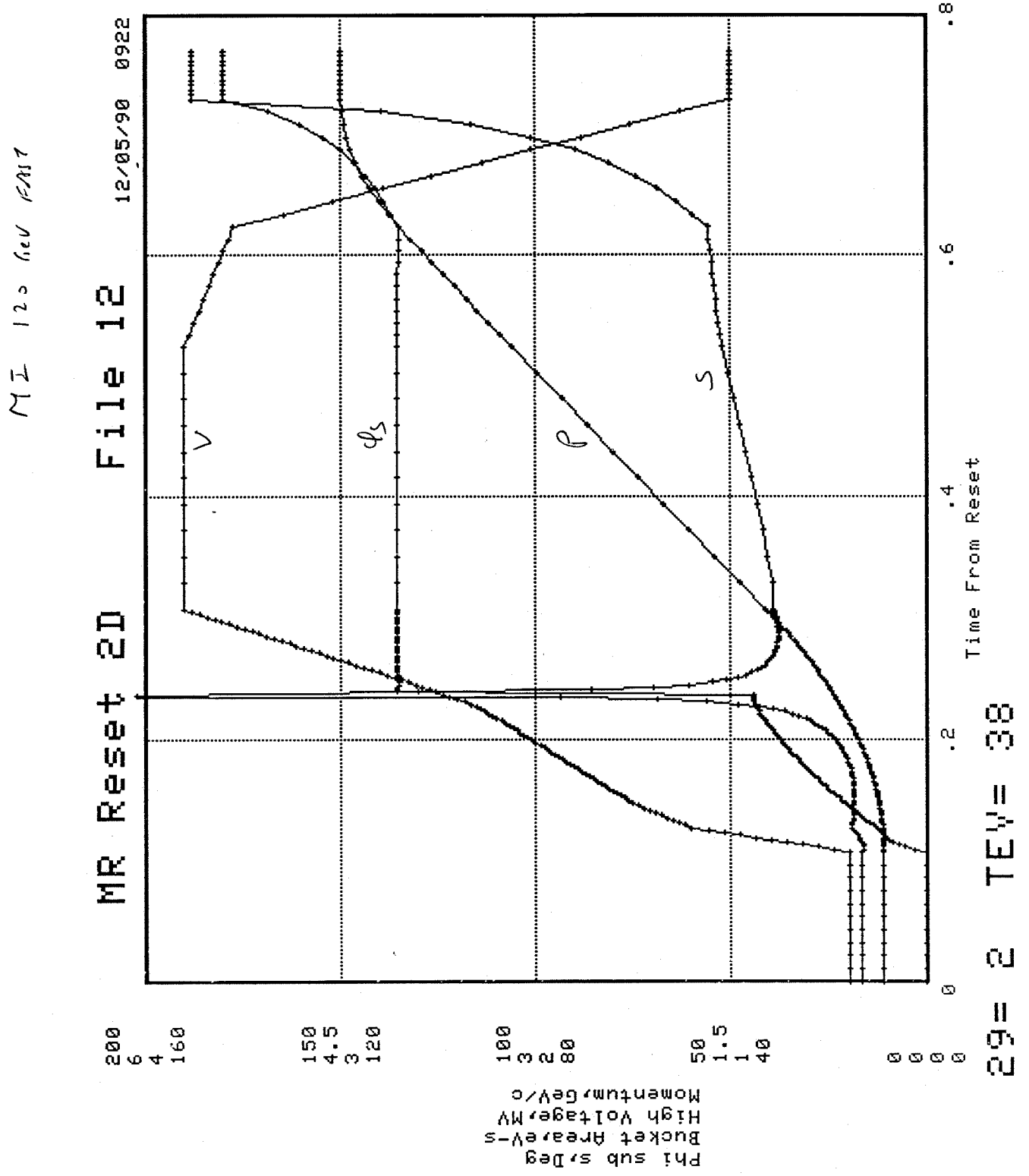
CONSOLE LOCATION 03; MCR-N2 5-DEC-1990 10:11
Main color TV

MI 120 GeV – FAST + SLOW

M3.05 Change Constants
*return
RESET(2D)

Max ramp slew rate (GeV/c/sec)	250	
Bend resistance (V/ GeV/c) ...	18.9333	⇒ .32 Ω
Quad resistance (V/ GeV/c) ...	9.7500002	
Bend inductance (V-sec/ Gev/c)	36.269199	⇒ .613 H
Quad inductance (V-sec/ Gev/c)	2.5999999	
Glitch start momentum (GeV/c)	8.8999998	
Glitch stop momentum (GeV/c)	50	
Glitch amplitude (V)	439.99999	
Max glitch slew rate (V/s) ...	15	
Bend current (Amp) / P (GeV/c)	59.166699	⇒ 7100 A = 120 GeV
Voltage curvature (V/s-2)	400000	
VPARAB length (sec)	0	
Bend voltage offset (<+-100V).	81.999999	

CONSOLE LOCATION 05; MCRLib 5-DEC-1990 09:22
MR Reset 2D File 12

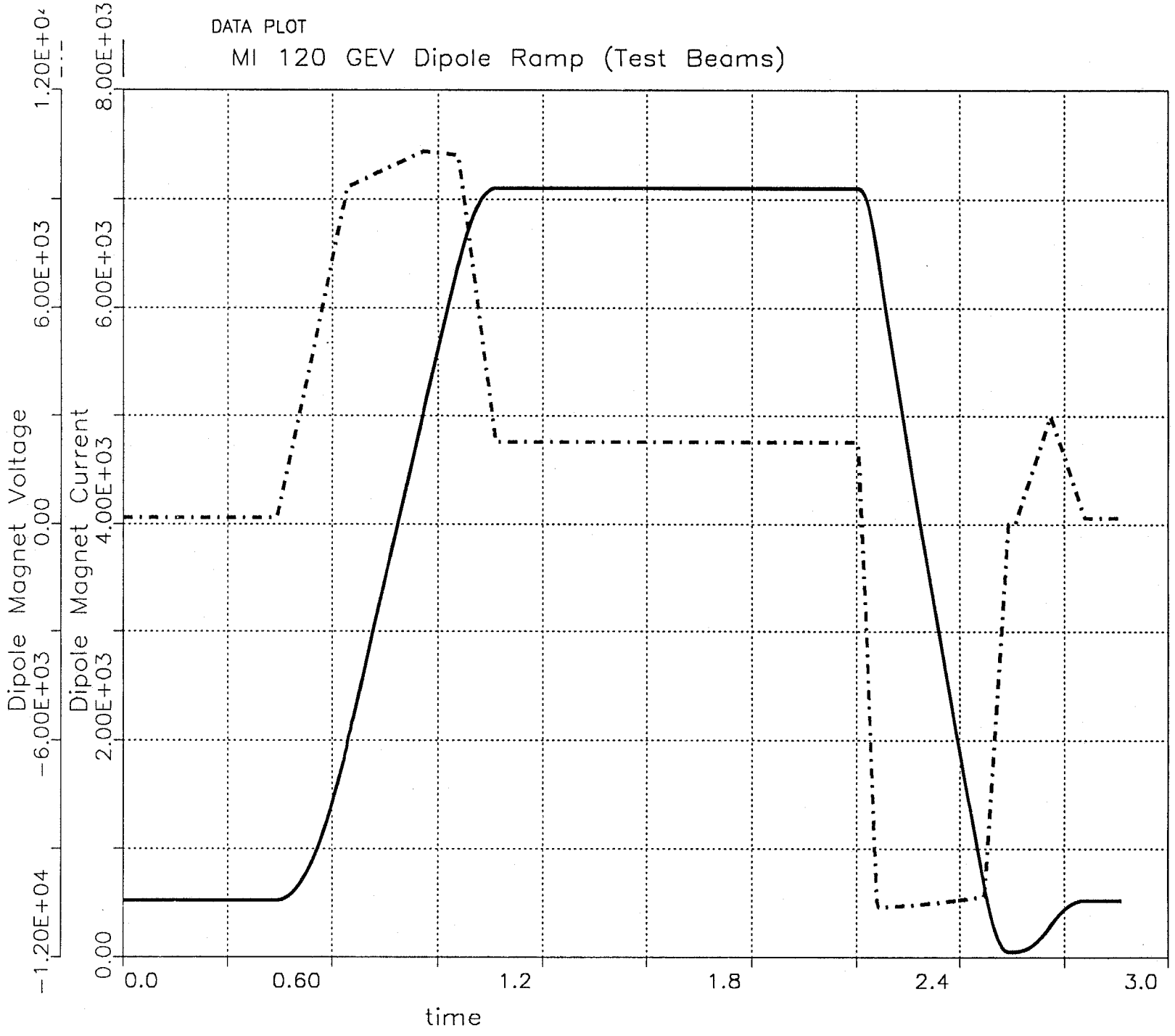


CONSOLE LOCATION 05; MCRLib 5-DEC-1990 09:22
Main color TV

M3.03 MODIFY file 12 MAIN INJ 120 GEV FAST-DO NOT LOAD!!!!!
*file dir *CH-RF *ch-plot *ch-const *ch-ramp *ch-chrom *ch-rag
RESET(2D) *calc *delete *insert

----------values at end of sequence----------

SEQ	TYPE	Dt	TIME	P	Pdot	%dP/P	PHI	HV18	AREA	%HITE
01	Initi>	.001	.001	8.889	0	0	0	>.393	.504	.236
02	Tramp>	.107	.108	8.889	0	0	0	>.393	.504	.236
03	Pramp	.02	.128	>9.129	24	0	13	>1.2	.584	.347
04	Pramp	.02	.148	>9.849	48	0	21	>1.5	.567	.357
05	Pramp	.02	.168	>11.049	72	0	28	>1.7	.568	.363
06	Pramp	.02	.188	>12.729	96	0	34	>1.9	.626	.39
07	Pramp	.02	.208	>14.889	120	0	39	>2.1	.774	.46
08	Pramp	.02	.228	>17.529	144	0	44	>2.3	1.28	.714
09	Pramp	.02	.248	>20.649	168	0	45	>2.65	1.65	.795
10	Pramp	.02	.268	>24.249	192	0	44	>3.04	1.19	.486
11	Pramp	.02	.288	>28.329	216	0	44	>3.42	1.14	.397
12	Pramp	.02	.308	>32.889	240	0	44	>3.8	1.17	.352
13	Pramp	.21713	.52513	>85	240	0	44	>3.8	1.57	.183
14	Pramp	.09892	.62405	>108	225	0	45	>3.55	1.67	.154
15	Pramp	.10667	.73072	>120	0	0	0	>1	5.65	.196
16	Tramp>	.04	.77072	120	0	0	0	>1	5.65	.196


DATA PLOT
MI 120 GEV Dipole Ramp (Test Beams)
Dipole Magnet Voltage
1.20E+04
6.00E+03
0.00
-6.00E+03
-1.20E+04
Dipole Magnet Current
8.00E+03
6.00E+03
4.00E+03
2.00E+03
0.00
0.0
0.60
1.2
1.8
2.4
3.0
time

RAMP POWER CALCULATIONS PROGRAM

INPUT DATA :

Ring current/energy ratio (amps/GEV) = 59.170
Total ring inductance (Henry) = 0.61300
Total ring resistance (ohms) = 0.32000
Desired Max. Operating Voltage for Holding PS = 0.100E+04
Desired Max. Operating Voltage for Ramping PSs = 0.100E+04
Number of power supplies = 12
Maximum Voltage Available from Holding PS = 1100.0
Maximum Voltage Available from Ramping PS = 1100.0
Feeder Voltage (line-to-line) = 13800.
The Power Supply Turn-on order:
1 3 12 12 12 12 12 12 12 12 12 12

Number of lines in ramp description = 14
The following are the ramp parameters:

TIME	+MOMENTUM+	***Pdot***	+++Pddot++
0.44100	8.8890	0.00000	0.00000
0.64100	32.889	240.00	1200.0
0.85713	85.000	240.00	0.00000
0.95705	108.00	225.00	-151.63
1.0637	120.00	0.00000	-2109.4
2.1037	120.00	0.00000	0.00000
2.1609	110.00	-350.00	-6125.0
2.4702	11.000	-290.00	193.94
2.5399	0.90000	0.00000	4163.4
2.5599	0.90000	0.00000	0.00000
2.6599	4.9000	80.000	800.00
2.6605	4.9490	80.000	0.00000
2.7590	8.8890	0.00000	-812.18
2.8667	8.8890	0.00000	0.00000

RAMP CALCULATIONS :

Peak ramp current (amps) = 7100.4
Total RMS ramp current (amps) = 4987.8
Min. and max. ramp voltage (volts) = -10625. 10314.
Maximum number of power supplies = 12
Ramp power (watts) = 0.79609E+07

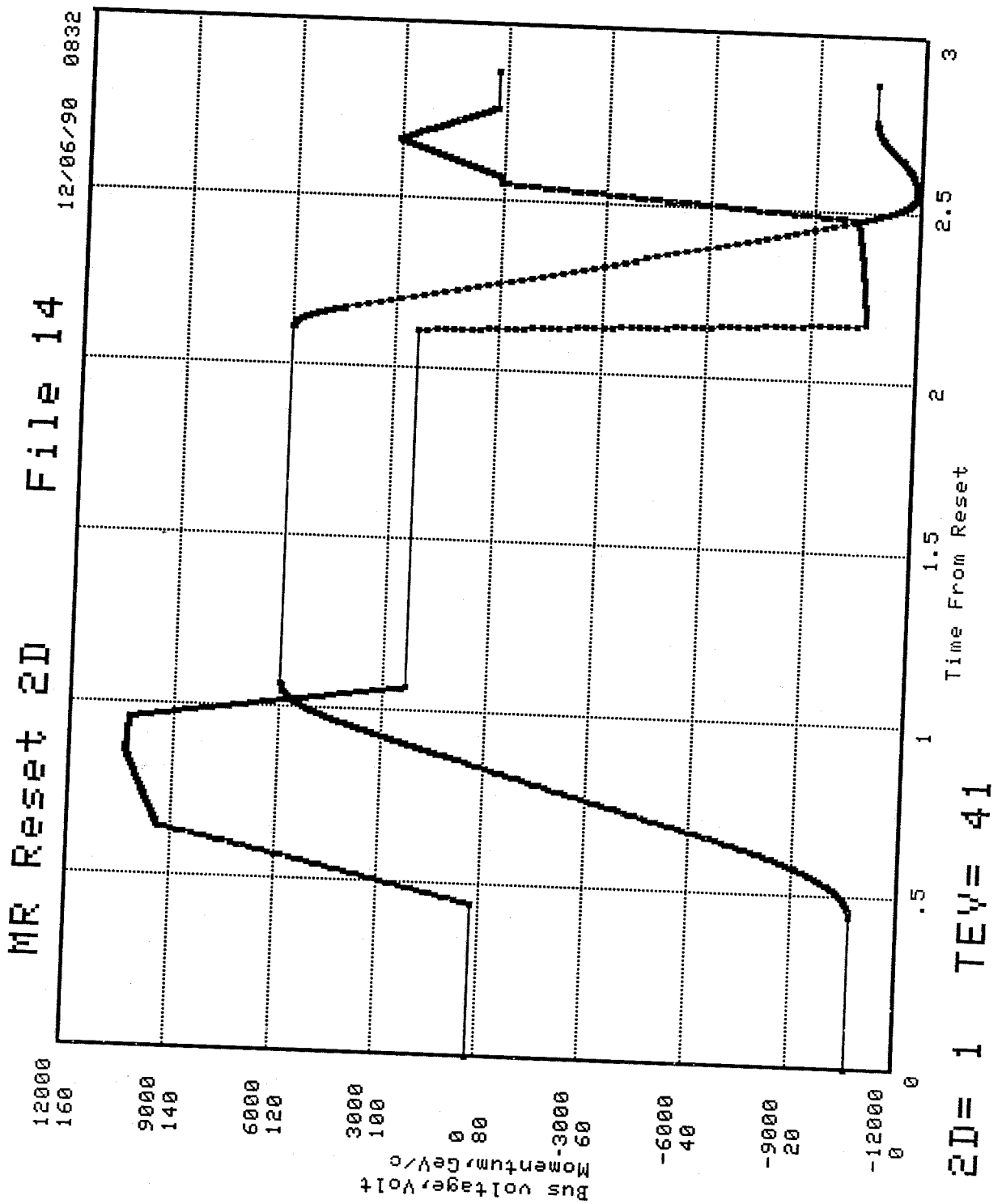
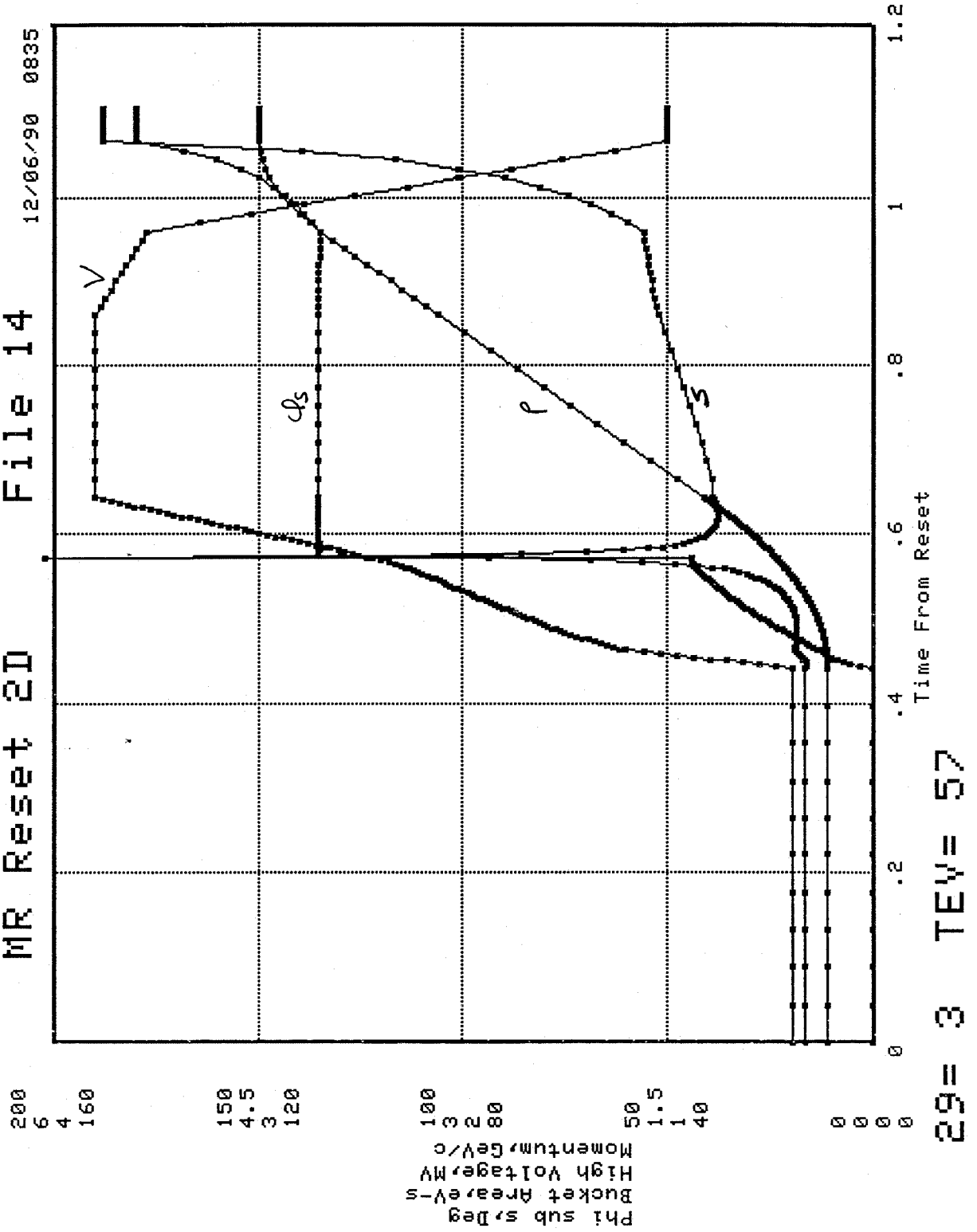
FEEDER CALCULATIONS :

Peak feeder current (amps) = 3918.0
RMS feeder current (amps) = 1473.4
Peak feeder volt-amps (v-a) = 0.93648E+08
Average feeder volt-amps (v-a) = 0.35217E+08

CONSOLE LOCATION 36; MCRLib
MR Reset 2D File 14

6-DEC-1990 08:34

MI - 120 GeV Scan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MR Reset 2D File 14