Power Supplies for Precooler Ring

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Eight power supplies will energize the antiproton Precooler ring. There will be two series connected supplies per quadrant. These supplies will power 32 dipole and 19 quadrupole magnets. The resistance and inductance per quadrant is R = 1.4045 Ohms and L = 0.466 Henries. Each power supply will have 12-phase series bridge rectifiers and will be energized from the 480 V 3-phase grid.

The total of eight power supplies are numbered IA, IIA, IIIA, IVA, and IB, IIB, IIIB, and IVB. Each quadrant will contain one "A" and one "B" supply. A block diagram of the Precooler ring with its power supplies is shown in Fig. 1.

1. Cooling Cycle

During the cooling cycle, Fig. 2, only the "A" supplies will be used. The "B" supplies will be bypassed.

1.1 94 A (0.2 GeV) Flattop (Bunch and transfer to ECR)

The injection current level of 94 A, (0.2 GeV) (8.2% of peak current), requires a voltage of 130 V, (8.9% of peak voltage), per quadrant. This level can be maintained by either charging the power supply filter capacitors with current spikes or by bypassing most of the power supplies in the other quadrants. We also could consider operating half the power supplies as rectifiers and half as inverters.

1.2 <u>94 A (0.2 GeV) to 660 A (4.5 GeV)</u> (Begin new cycle)

To raise the current from 94 A to 660 A, in 0.5 sec, requires a voltage jump from 130 V to 663 V, and then an exponential voltage rise to 1458 V (660 A) per quadrant. The "A" supplies will operate under phase control following a $\dot{B}$ reference.

1.3 <u>660 A (4.5 GeV) Flattop</u> (First Cooling)

To maintain the 660 A current level the "A" supplies will be phased back to $\alpha = 50^{\circ}$ providing 925 V per quadrant.

1.4 <u>660 A (4.5 Gev) to 437 A (2.6 GeV)</u> (Deceleration)

To go from 660 A to 437 A at a rate of 1139 A/s requires the voltage, per quadrant, to drop from 925 V ($\alpha = 50^{\circ}$) to 395 V ($\alpha = 74^{\circ}$), and then decrease exponentially to 82.5 V ($\alpha = 86^{\circ}$). The "A" supplies will operate under phase control from a $\dot{B}$ reference.

1.5 <u>437 A (2.6 GeV) Flattop</u> (Second Cooling)

When the current reaches 437 A the voltage, per quadrant, must jump from 82.5 V ($\alpha = 86^{\circ}$) to 600 V ($\alpha = 69^{\circ}$). For a better power factor, the supplies in two quadrants could operate as rectifiers while the other two supplies operate as inverters. One could also bypass the supplies in two quadrants and operate the remaining two supplies as rectifiers at a phase angle of $\alpha = 35^{\circ}$ providing 1200 V for two quadrants.

1.6 <u>437 A (2.6 GeV) to 246 V (1.3 GeV)</u> (Deceleration)

The voltage across a quadrant of magnets must drop from 600 V to 82.5 V and then decrease exponentially to -185 V. If all four "A" supplies are on and operating at 600 V ($\alpha = 69^{\circ}$), the phase angle must increase to $\alpha = 86^{\circ}$ for 82.5 V, and then to $\alpha = 97^{\circ}$ for -185 V. If two supplies are bypassed the remaining two supplies must operate at $\alpha = 83^{\circ}$ for 165 V, (2 x 82.5 V), and $\alpha = 105^{\circ}$ for -370 V, (2 x -165 V). The "A" supplies will operate under phase control from a $\dot{B}$ reference.

1.7 <u>246 A (1.3 GeV) Flattop</u> (Third Cooling)

When the current has decayed to 246 A, the four "A" power supplies are phased to operate with $\alpha = 76^{\circ}$ providing 345 V per quadrant. If only two supplies are operatng the phase angle of each supply would be $\alpha = 61^{\circ}$ for 690 V for two quadrants.

1.8 <u>246 A (1.3 GeV) to 94 A (0.2 GeV)</u>(Deceleration)

To decrease the current from 246 A to 94 A requires a voltage drop from 345 V, per quadrant, to -185 V and then an exponentially decreasing voltage to -398 V. With four "A" supplies operating, the phase angle of each supply must go from $\alpha = 76^{\circ}$ for 345 V to $\alpha = 97^{\circ}$ for -185 V, and then to $\alpha = 106^{\circ}$ for -398 V. If only two "A" supplies are operating the phase angle of each supply must go from $\alpha = 61^{\circ}$ for 690 V per two quadrants to $\alpha = 105^{\circ}$ for -370 V per two quadrants, and then to $\alpha = 123^{\circ}$ for -796 V per two quadrants. The "A" supplies will operate under phase control from a $\dot{B}$ reference.

2. Once Every 5 Hours Acceleration to 8 GeV

With all the antiprotons in the Electron Cooling Ring and the Precooler deenergized a reversing switch changes the polarity of the power supplies. The acceleration-cycle waveform is shown in Fig. 3.

2.1 Injection Current of 94 A (0.2 GeV) (Raise field to injection level)

Either the type "A" or the type "B" supplies can be used to obtain the injection current of 94 A. If the "B" supplies are used, they must be phased-on to produce a voltage of 530 V per quadrant ($\alpha = 37^{o}$) and then be exponentially increased to produce 663 V ($\alpha = 9^{o}$) per quadrant. The current rises from zero amperes to 94 A in 82 ms at a rate of 1139 A/s.

2.2 94 A (0.2 GeV) Flattop (Injection)

When the current reaches 94 A the "B" supplies are phased back to produce 130 V per quadrant ($\alpha = 78^{o}$). Alternatively the voltage for this level can be maintained as described in 1.1.

2.3 94 A (0.2 GeV) to 1139 A (8.2 GeV) Acceleration

For acceleration to 8 GeV the four "A" and the four "B" supplies are required. The power supply output voltage per quadrant must jump from 130 V to 663 V and then rise exponentially to 2130 V. The current will rise at a rate of 1139 A/s. The "A" and "B" supplies will operate under phase control following a $\dot{B}$ reference signal.

2.4 1139 A (8 GeV) Flattop (Transfer manipulations to Tevatron)

When the current has reached 1139 A, in about one second, the supplies are phased back to produce 1.575 kV per quadrant ($\alpha = 42^{o}$).

2.5 1139 A to 0 A (Discharge of Magnets)

By means of rectifier phase control the output voltage of the power supplies is reduced thereby forcing the current to zero at a rate determined by a $\dot{B}$ reference signal. Some of the 1.2 MJ stored in the magnets is returned to the power grid when the power supply voltages go negative.

3. Tune-up Cycles

The antiprotons will be collected at 4.5 GeV (660 A) for precooling and transferred to the Electron Cooling Ring at 0.2 GeV (94 A). After electron cooling and accumulation the antiprotons will be transferred back to the Precooler at 0.2 GeV, preaccelerated to 8 GeV (1139 A), and injected into the Tevatron. It may be desirable to experiment at one or more of the above energy levels during tune-up.

4. Cost Estimates for Power Supplies

The power supply ratings (sizes) and costs depend not only on the "normal" cycle but also on what tune-up cycles are required. Three cases have been evaluated.

4.1 Power Supplies Required for Normal Operation

To perform the pulsing duties outlined in Sections 1 and 2 above, each type "A" and each type "B" power supply has an rms current rating of 445 A. The rating of their thyristor assemblies, which have a short thermal time constant, is determined by the 3 s flattop of 1139 A. Characteristics and costs of these power supplies are shown in Table I. For tune-up purposes these power supplies can be pulsed with flattops of 1 s duration at the following repetition rates:

94 A to 600 A (0.2 to 4.5 GeV) every 3 s,
94 A to 1139 A (0.2 to 8 GeV) every 11 s.

4.2 Power Supplies for Pulsed and Continuous Operation at 4.5 GeV (660 A)

In order to be able to collect antiprotons continuously the Precooler would be energized with 660 A dc. This requires type "A" supplies rated 611 kW. Of course this also assumes that the magnets can carry 660 A continuously.

The repetition rate for pulsing from 0.2 GeV to 8 GeV is the same as under 4.1 because this is determined by the rating of both the type "A" and the type "B" supplies. Characteristics and costs of the 611 kW type "A" supply are given in Table I.

4.3 Power Supplies for Pulsed and Continuous Operation at 8 GeV (1139 A)

For completness sake we have added to Table I the characteristics and costs of power supplies capable of running at 1139 A continuously. This mode of operation could be approximated if injection of antiprotons into the Tevatron is done over a very long time.

Table I
Power Supply Options

1. **Power Supplies for Normal Pulsed Operation**
   (I^2R losses per quadrant 278 kW)

Type "A" Supply

Maximum dc output voltage	1458 V
Maximum dc output current	1139 A
Maximum dc output power	1.66 MW
RMS output current	445 A
RMS rating	≥278 kW

Type "B" Supply

Maximum dc output voltage	672 V
Maximum dc output current	1139 A
Maximum dc output power	0.765 MW
RMS output current (normal operation)	15 A
RMS rating (tune-up)	445 A, 128 kW

Tune-up With Flattop ≤ 1 s

0.2 GeV to 4.5 GeV repetition rate 3 s (type "A" supply only)

0.2 GeV to 8 GeV repetition rate 11 s (type "A" and B" supplies)

Cost of one Type "A" Supply	$ 60 K
Cost of one Type "B" Supply	$ 35 K

2. **Power Supplies for Pulsed Operation to 8 GeV and Continuous Operation at 4.5 GeV**

Type "A" Supply

Maximum dc output voltage	1458 V
Maximum dc output current	1139 A
Maximum dc output power	1.66 MW

Steady state dc output voltage	925 V
Steady state dc output current	660 A
Steady state dc output power	611 kW

Type "B" Supply

Same as for 1. above (128 kW)

Tune-up

4.5 GeV injection continuously

0.2 GeV to 8 GeV same as for 1 above

Cost of Type "A" Supply	$ 86 K
Cost of Type "B" Supply	$ 35 K

3. Power Supplies for Pulsed or Continuous Operation up to 8 GeV

Type "A" Supply

Maximum dc output voltage	1458 V
Maximum dc output current	1139 A
Peak dc output power	1.66 MW
Steady state dc output voltage (8 GeV)	1077 V
Steady state dc output current (8 GeV)	1139 A
Steady state dc output power (8 GeV)	1.23 MW

Type "B" Supply

Maximum dc output voltage	672 V
Maximum dc output current	1139 A
Maximum dc output power	765 kW

Steady state dc output voltage (8 GeV)	497 V
Steady state dc output current (8 Ge)	1139 A
Steady state dc output power (8 GeV)	566 kW
Cost of one Type "A" Supply	$148 K
Cost of one Type "B" Supply	$ 70 K

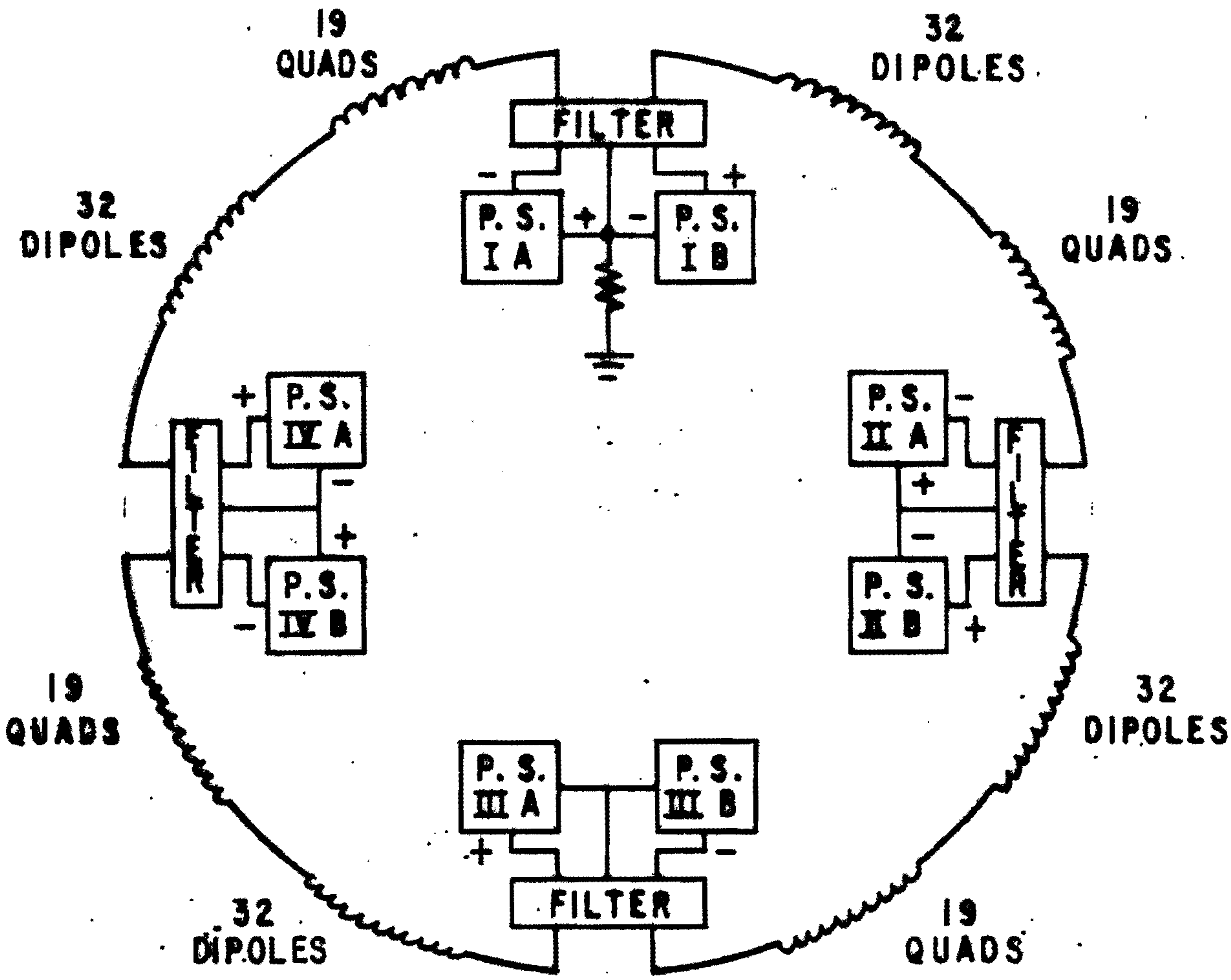

FIG. I BLOCK DIAGRAM OF PRECOOLER POWER SUPPLY

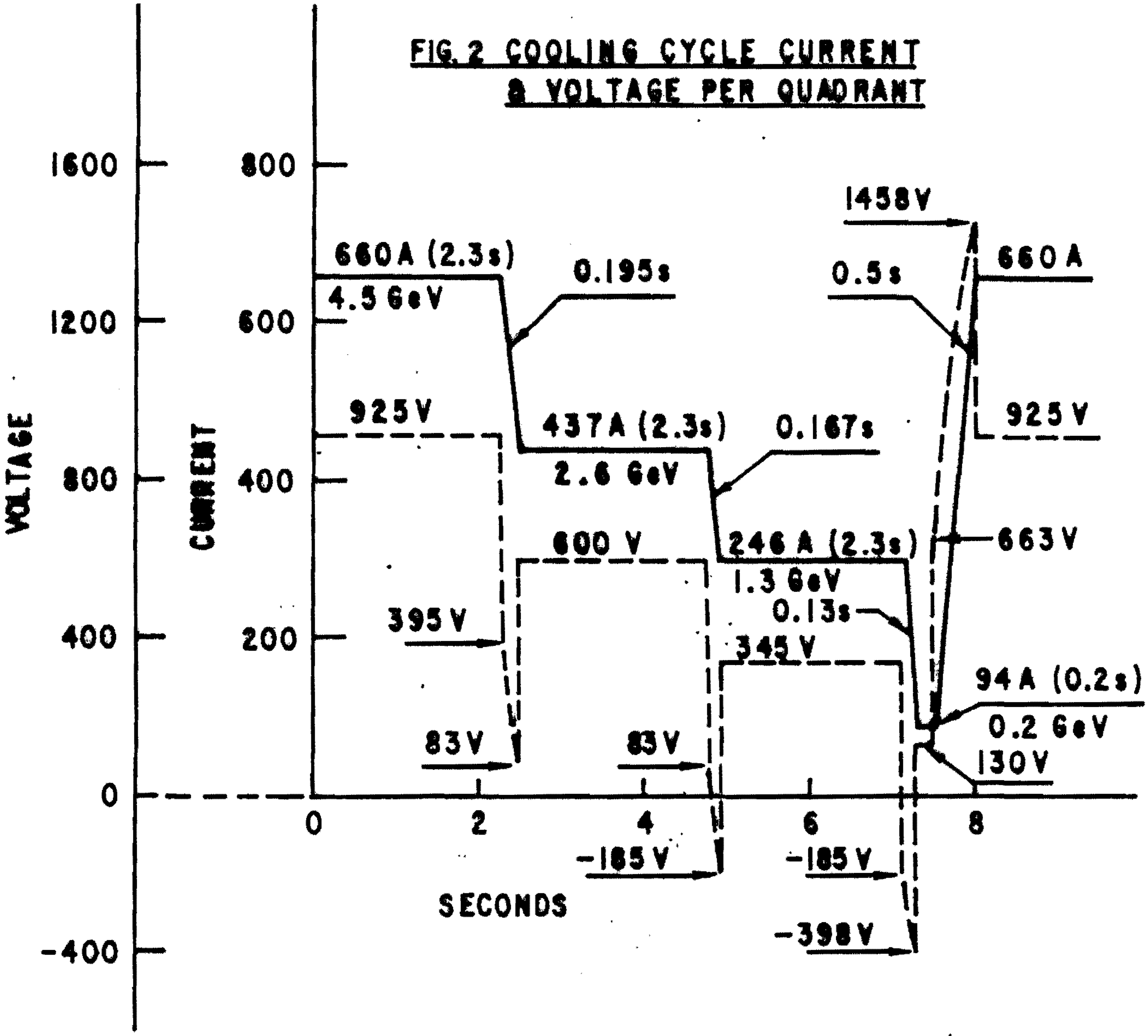

FIG. 2 COOLING CYCLE CURRENT & VOLTAGE PER QUADRANT
VOLTAGE
CURRENT
SECONDS
1600
1200
800
400
0
-400
800
600
400
200
0
2
4
6
8
660A (2.3s)
4.5 GeV
0.195s
925V
437A (2.3s)
2.6 GeV
0.167s
600 V
395 V
83V
83V
246 A (2.3s)
1.3 GeV
0.13s
345 V
-185 V
-185 V
-398 V
1458V
0.5s
660 A
925 V
663 V
94 A (0.2s)
0.2 GeV
130V

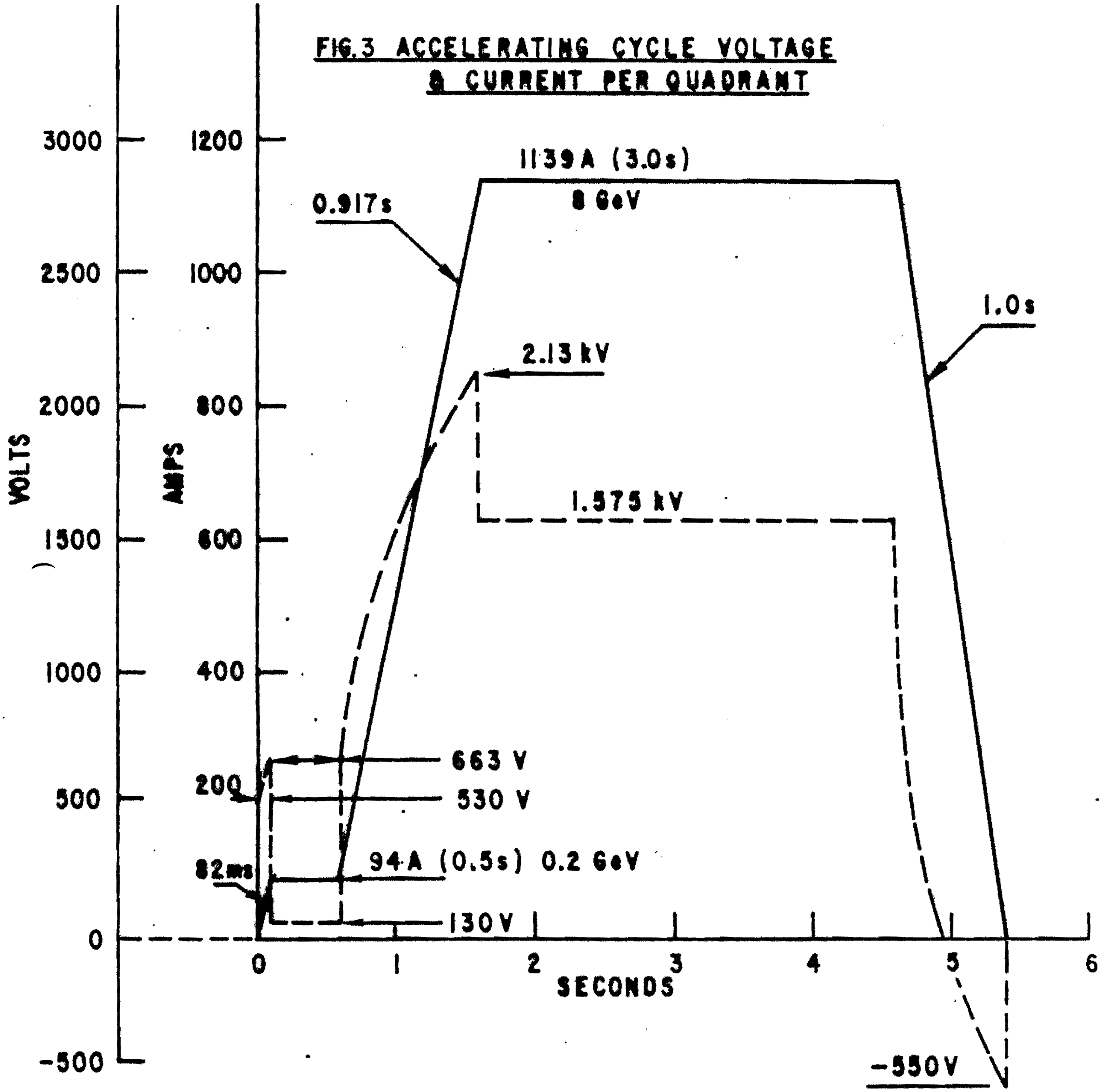
FIG.3 ACCELERATING CYCLE VOLTAGE & CURRENT PER QUADRANT
1139 A (3.0s)
8 GeV
0.917s
1.0s
2.13 kV
1.575 kV
663 V
530 V
94 A (0.5s) 0.2 GeV
82ms
130 V
-550V
VOLTS
AMPS
SECONDS
3000
2500
2000
1500
1000
500
0
-500
1200
1000
800
600
400
200
0
1
2
3
4
5
6