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Power Consumption During a Typical 24-Hour Accelerator Cycle

J. Gannon, R. Harold, C. Jach, F. Meyer, C. Rostamzadeh
SSC Accelerator Electrical Engineering Group

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ABSTRACT

This note will describe a typical operating cycle for a 24-hour period when the machine is operating for the experiments and providing test beams. The major loads of the injectors, if curtailed to minimum levels when not needed, provide a savings of 327 MWh of electricity a day. This synchronized curtailment of power also reduces the demand on the power distribution system while the Collider is ramping. Loads are described in detail so that feeder currents and load flows versus time can be understood. This scheme is not typical of the operation at other facilities and is possible because of the long ramping times of the HEB and Collider. The magnet power supply regulation systems need to be designed for this type of operation so that the savings can be realized.

Introduction

Electric power consumption during machine operation is a major factor in determining the hours per year that an accelerator may be operated. Efficient use of electric power can allow the laboratory to better utilize operating funds. Operating large loads only when necessary reduces the demands on the air conditioner distribution both on- and offsite by reducing peak and average loads.

Previous machines, like the ones at Fermilab and CERN, required their injectors to constantly cycle for stability and other necessary uses, such as antiproton production. The Superconducting Super Collider (SSC) cycle allows substantial savings to be made if the systems are designed for the type of operation outlined in this report.

Calculations in this report are based on several basic assumptions that allow for power savings and reduced demand on the distribution system. These assumptions are:

1. The Low, Medium, and High Energy Boosters (LEB, MEB, and HEB) are not ramped when the Collider is being ramped up to or down from 20 TeV. They are also not ramped while the low beta squeeze and other experimental setups are taking place once the beams reach 20 TeV. This reduces the peak demand on the power grid by more than 180 MVA. The machine operators will probably be busy during this period anyway and therefore this would be wasted energy.

2. Test beam magnets are only used when the Collider is not operating or is at 20 TeV. The test beam is never ramped when the Collider setup is in progress.

3. When the HEB is operating for test beams and has a 3-minute cycle, the LEB and MEB are ramped to injection levels while the HEB is ramping. This results in substantial power savings during a long period.

Table 1 shows the loads for the major technical systems of the accelerator. These are the magnet power systems, the RF systems, and the cryogenic systems. Systems such as experimental detectors, cooling water, controls, vacuum, etc., which are relatively constant are not included in this summary.

Table 1
Technical Systems Electrical Loads

Accelerator System	Peak MVA	Average MVA	Max Avg Pwr (MW)	24-hr Cycle Avg Pwr (MW)
Linac	3.1	3.1	2.8	2.8
LEB	10.5	7.8	6.3	1.4
MEB	116.5	45.3	22.1	3.8
HEB	78.8	47.9	16.0	15.3
Test Beams	60.8	21.2	18.0	15.0
Collider	112.0	80.9	58.0	58.0
Total			123.2	96.3

If the LEB, MEB, HEB, and test beams were left ramping while the Collider ramps, and the cycle times were such that all the machines were at peak load at the same time, a peak load of 327 MVA would be realized from the major technical loads. If one adds to this the other loads of the system, a very large peak load would indeed be realized which would probably cause excessive line droop. With those systems ramped to minimum power the peak would be lowered to 104 MVA, a much more reasonable figure.

Table 2 is a detailed description of the operating cycle that was used to calculate the power consumption. Table 3 shows details of the subsystem loads. The figures that follow show the magnet loads for each of the machines for various operating conditions.

Table 2

24-Hour Accelerator Operating Cycle for Physics

The following describes a typical 24-hour cycle, invented by the authors, when the machine is operated for physics and no accelerator studies or tests are being conducted with the injector machines.

Collider Fill – 1 hour 40 minutes
One hour to tune-up Injector and 40 minutes to fill Collider rings.
Conditions:

All injector devices operating with normal cycles for optimum stability
LEB RF, Kickers, etc. pulse nine times every three seconds.
MEB cycle time = 3.0 sec with 0.2-sec flattop
HEB cycle time = 120 sec with 10-sec flattop
Test beam magnets not ramping

Collider Ramp to Flattop –16.5 minutes
Conditions:

LEB, MEB, HEB and test beam magnets not ramping

Low Beta Squeeze and Beam Scraping – 30 minutes
Conditions:

LEB, MEB, and HEB still not ramping

Collider Operating for Physics – 21 hours and 20 minutes
Conditions:

MEB operates for 2 hours for test beam, with 4-sec cycle and 1-sec flattop. Allowing 1 hour for tune-up of test beams, experiments get 900 beam pulses. LEB-pulsed devices pulse nine times every 4 seconds, LEB main magnets ramping continuously. HEB is not ramping during this period.

HEB then operates 19 hours and 20 minutes for test beam, with 3-min cycle and 70-sec flattop. MEB operates with the same cycle as Collider fill mode (i.e., 3-sec cycle). Again allowing 1 hour of tune-up, experiments get 366 beam pulses. The MEB is only ramped three times at the beginning of the cycle and two times at the end of the HEB cycle to save power. The LEB is also ramped to zero current during this same period.

Collider Ramp to Injection Level – 13.5 minutes
Conditions:

Ramp down to injection level takes 8 minutes and 5.5 minutes for a pit stop and data saves.

Table 3
System Load Details

System	Peak MVA	Average MVA	Peak Pwr MW	Avg Pwr MW	Curtailed Pwr MW
Linac	3.1	3.1	2.8	2.8	2.8
LEB Mag	7.1	7.1	5.7	5.7	1.3
LEB Cor	0.2	0.1	0.1	0.1	0.02
LEB RF	3.2	0.6	3.0	0.53	0.1
L to M PS	0.5	0.5	0.4	0.4	0.1
MEB Mag	106.5	43.0	46.5	19.9/11.2	3.3
MEB Cor	0.3	0.1	0.3	0.2	0.04
MEB RF	9.7	2.2	8.7	2.0	0.5
M2 to H6 PS	7.9	3.2	3.5	1.5	0.25
M4 to H4 PS	16.2	6.5	7.0	3.0	0.5
HEB Mag	58.3	32.4	50.8	2.8/1.8	2.8
HEB Cor	2.1	0.7	1.9	0.5	0.4
HEB RF	4.4	3.0	4.0	2.7	2.7
HEB Cryo	14.0	11.8	10.0	10.0	10.0
H to C PS	3.7	3.7	3.3	3.3	0.3
Col Mag	50.0	22.0	4.0	2.0	2.0
Col Cor	4.0	2.2	2.0	2.0	2.0
Col RF	6.2	4.4	5.6	4.0	4.0
Col Cryo	52.3	52.3	47.9	47.9	47.9
TB PS	60.8	21.2	53.6	18.0	18.0

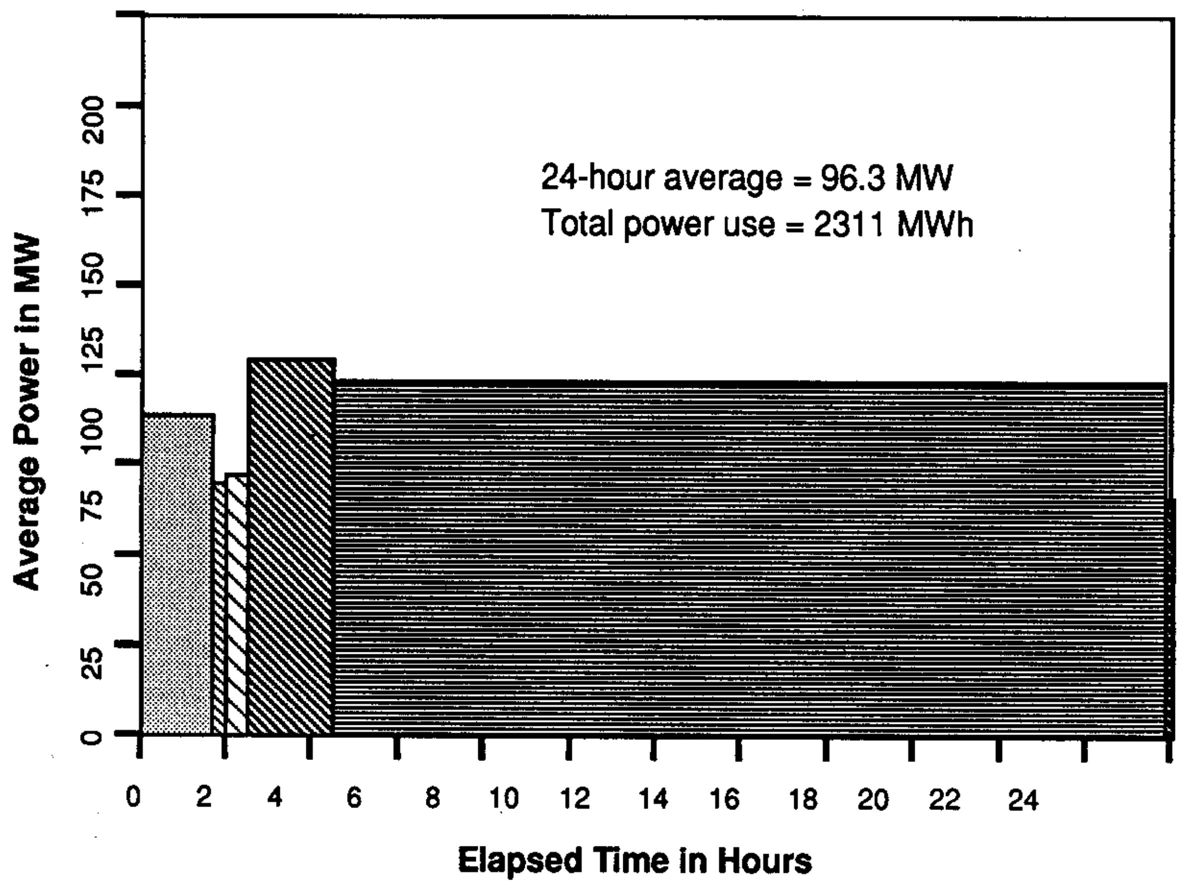

Figure 1. 24-Hour Cycle Average Power

Figure 1 is a histogram of the sum of the average systems power during the various periods of the 24-hour cycle previously described. This cycle consumes a total of 2311 MWh of electricity for the technical loads in a 24-hour period.

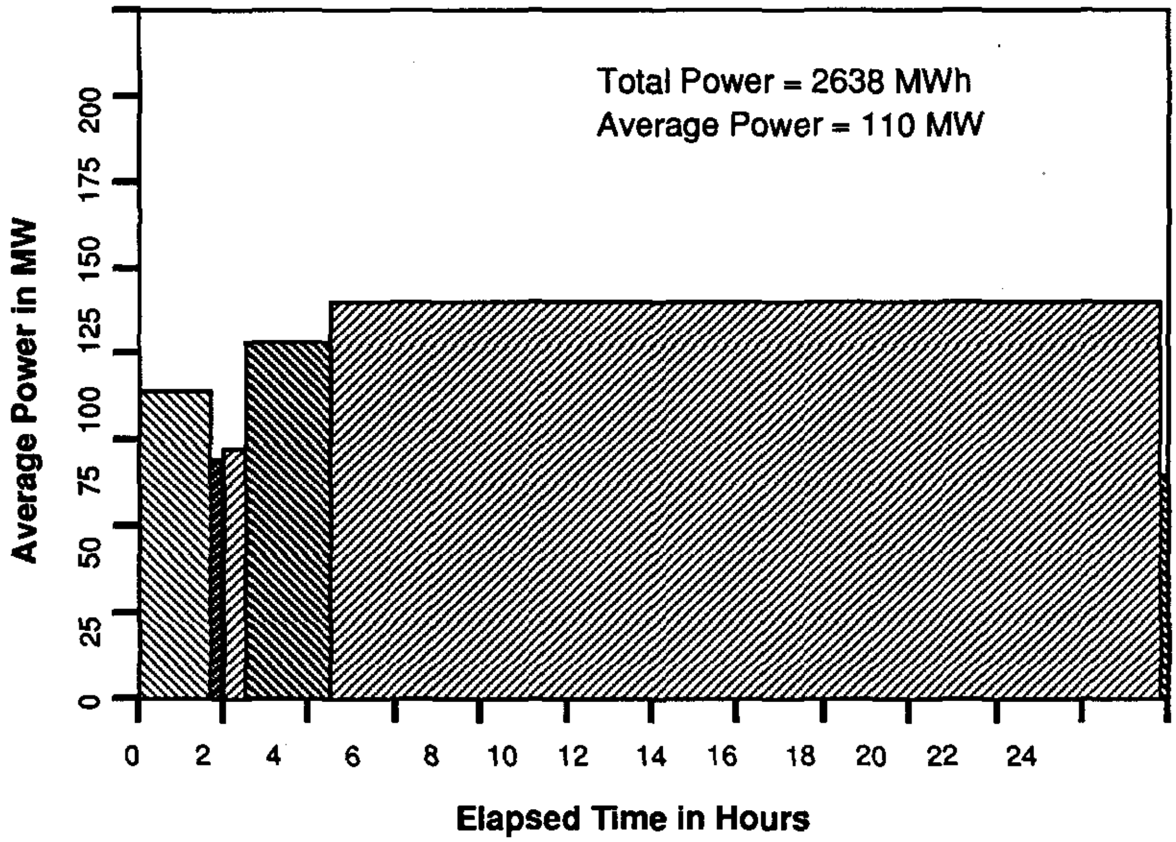

Figure 2. Average Power with LEB and MEB Ramping Continuously During Test Beam Operation

Figure 2 is a maximum power usage if the LEB and MEB are kept ramping continuously during test beam operation. Total power consumed during this cycle increases to 2638 MWh during the 24-hour cycle, or an increase of 327 MWh.

If the 200-GeV and 2-TeV test beams are run simultaneously, the power consumption is even higher. A worse-case consumption where all systems are exercised at maximum average power levels gives a total 24-hour usage of 2958 MWh of an increase of 646 MWh over the best case. Clearly the power consumption and operation mode of the facility must be optimized and monitored.

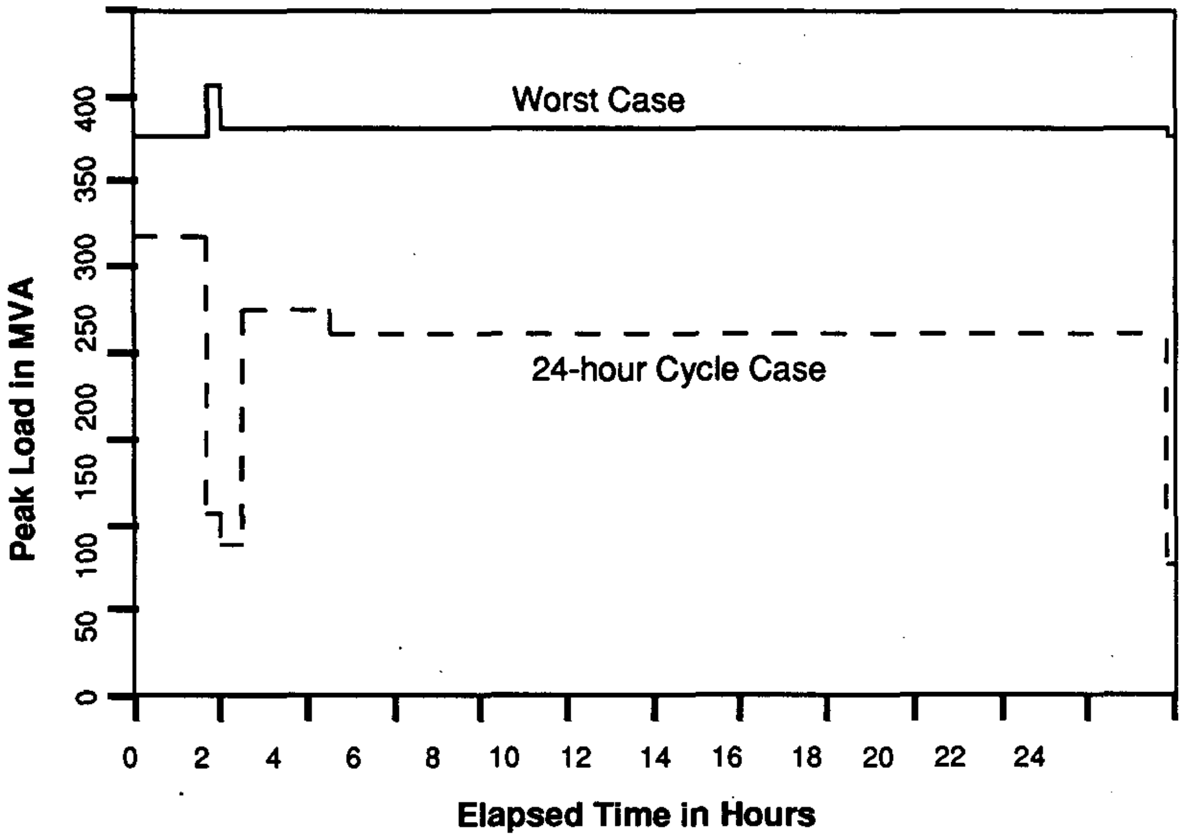

Figure 3. Peak Loads for 24-Hour Cycle and Worst-Case Operation

Figure 3 is the peak MVA possible if all loads are kept ramping and peaks coincide during the cycle.

LEB Magnet Power Supply Load

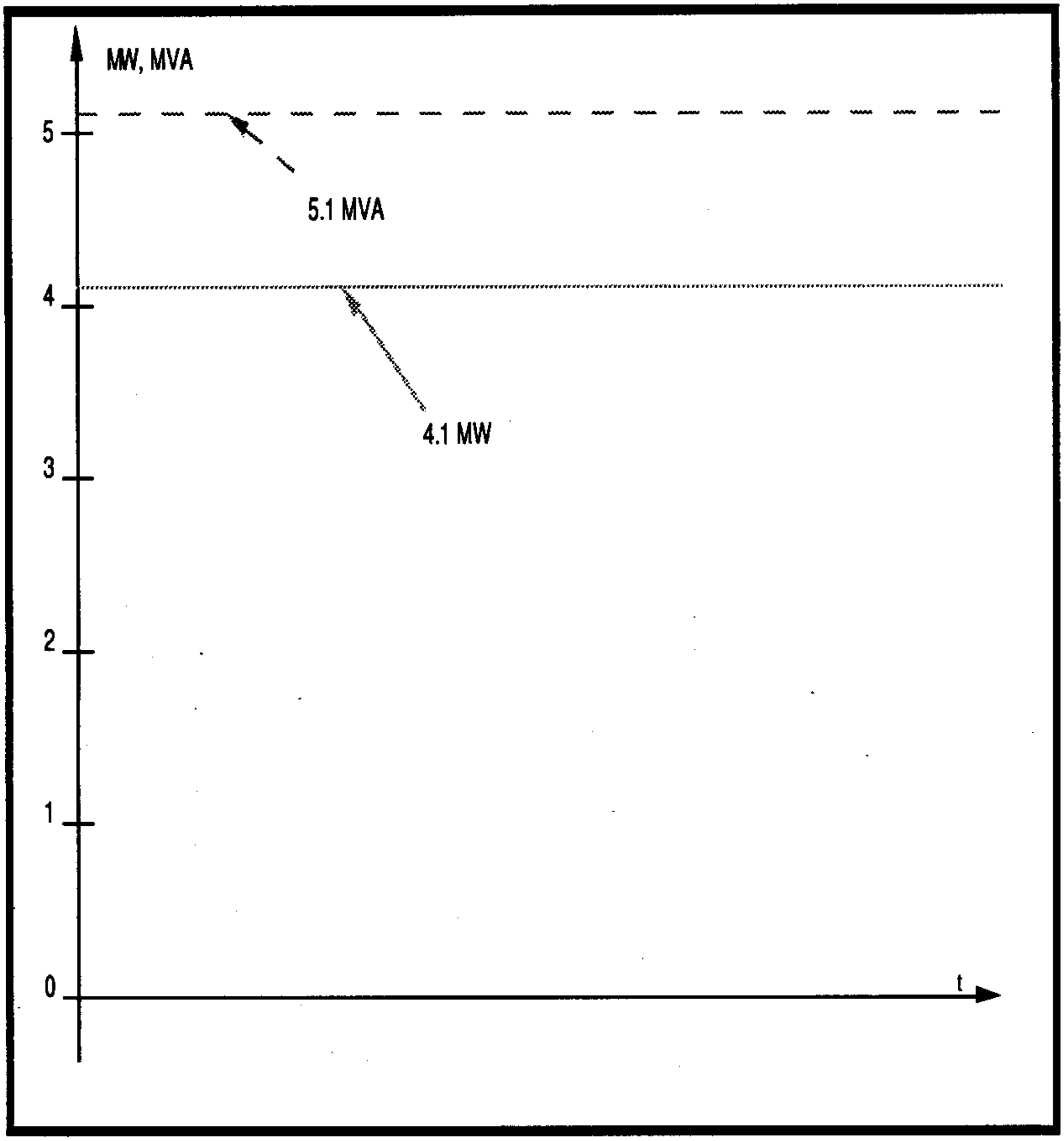

Figure 4. LEB Loads with Continuous Operation

This figure shows the peak magnet load for the LEB when the magnet is ramping continuously at 10 Hz.

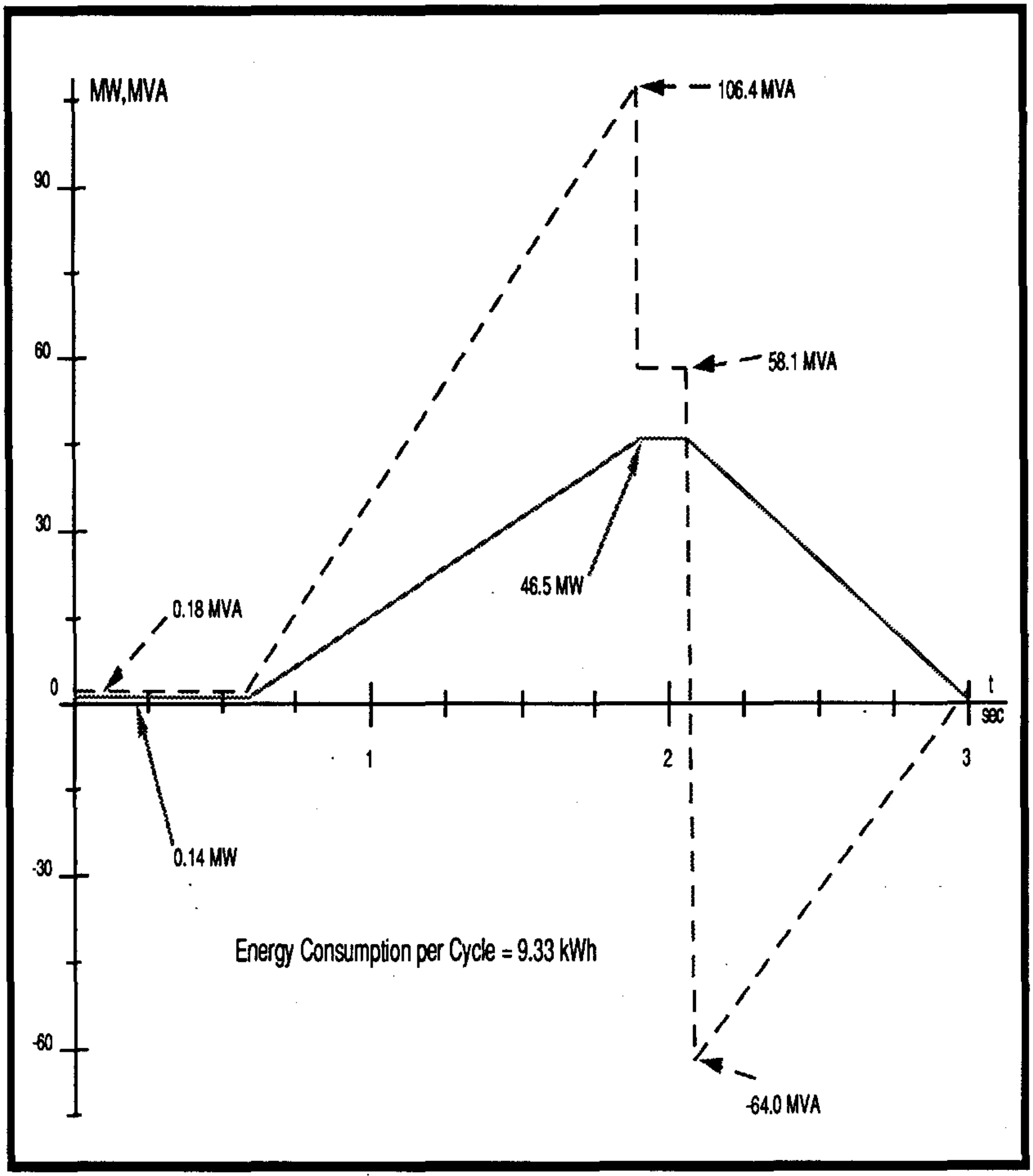

Figure 5. MEB Fast Cycle Magnet Power Supply Load

Figure 5 shows the magnet load for the MEB when it is used to fill the HEB. Average power for the entire MEB magnet system for this ramp is 11.2 MW.

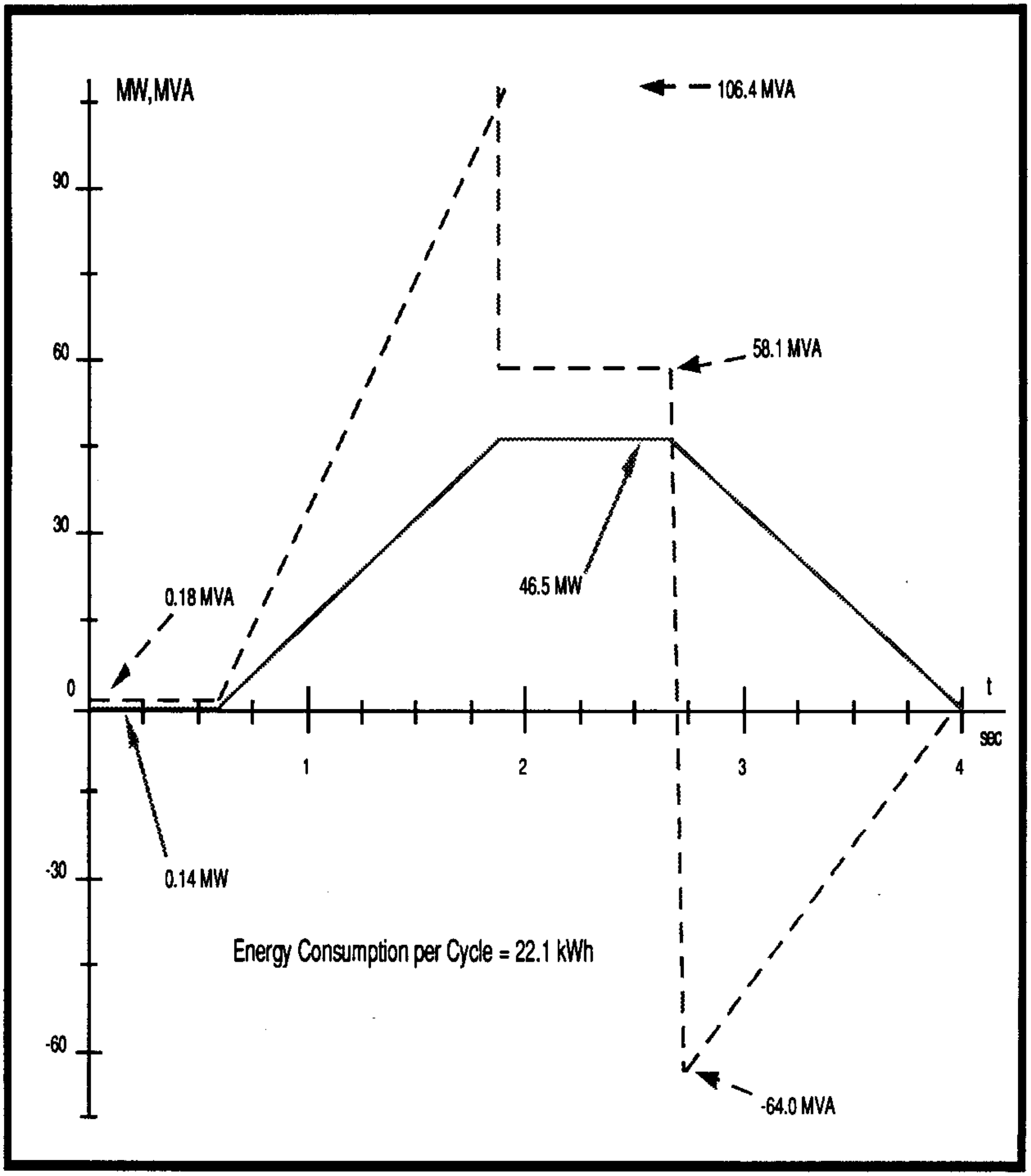

Figure 6. MEB Slow Cycle Magnet Power Supply Load

Figure 6 shows the magnet loads for the MEB when the beam is being delivered to the test beam area from the MEB. Average power for this cycle is 19.9 MW.

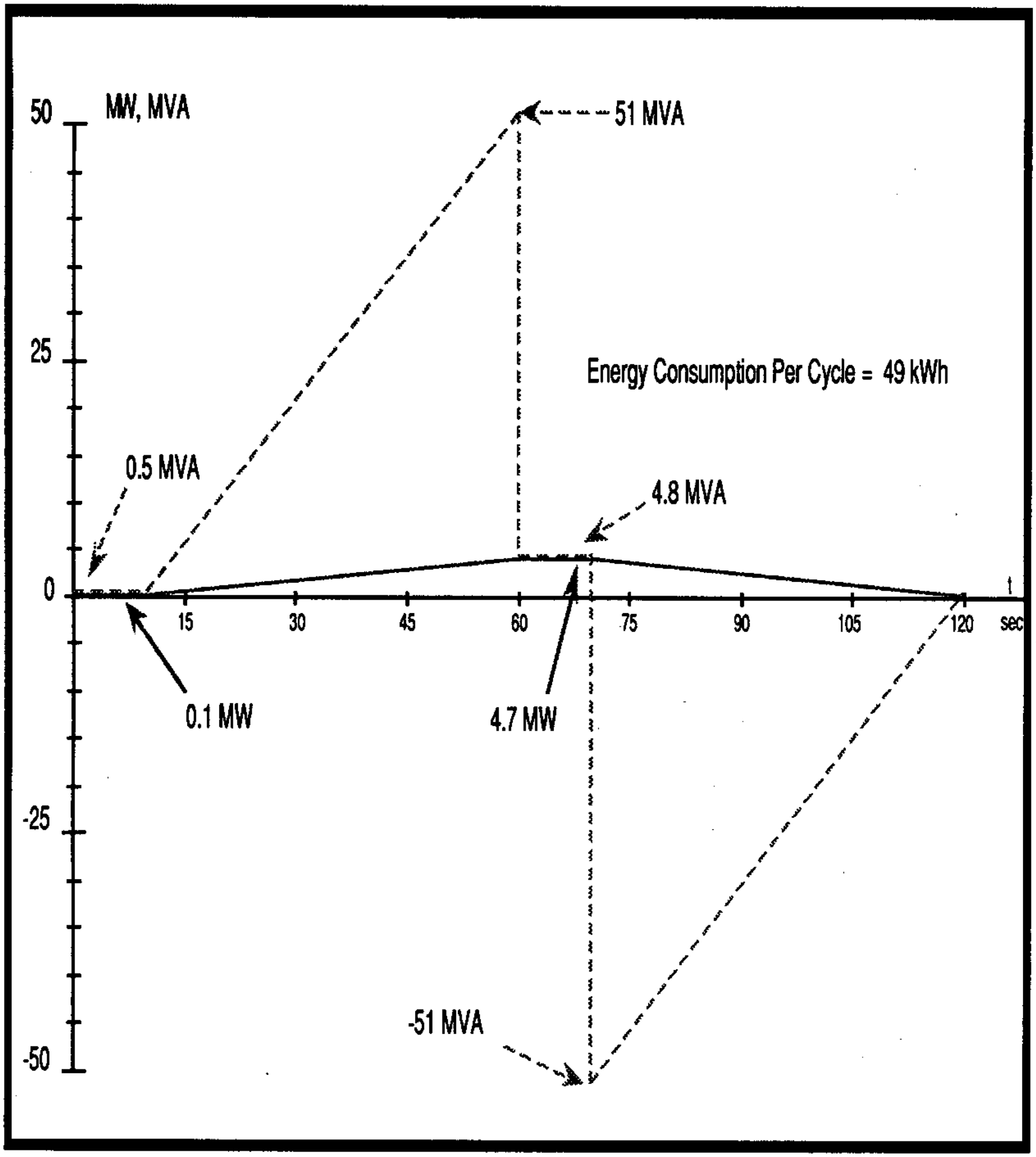

Figure 7. HEB Fast Cycle Magnet Power Supply

Figure 7 shows the HEB magnet load profile for the Collider fill cycle of the HEB. Total average power for this ramp is 1.8 MW.

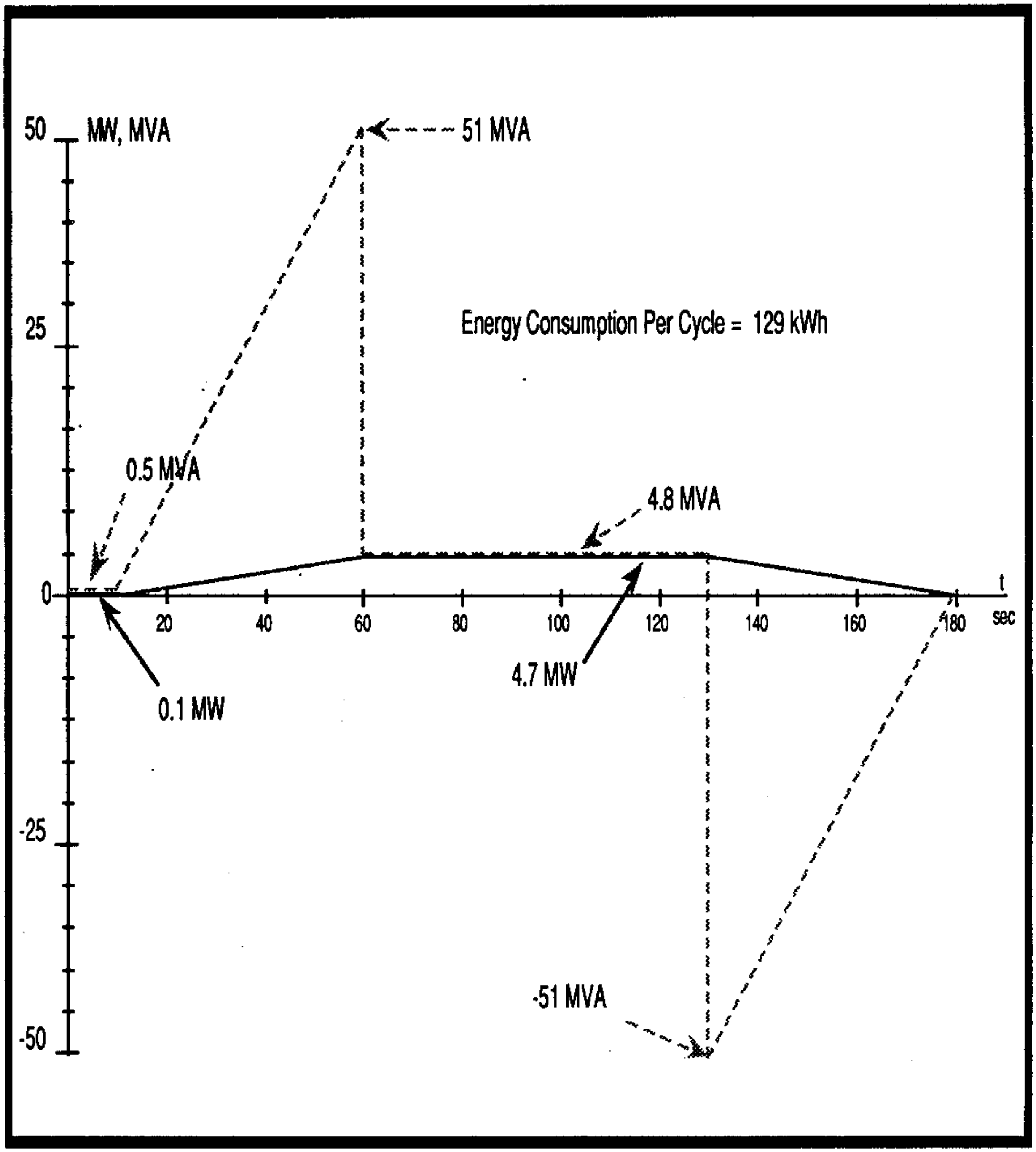

Figure 8. HEB Slow Cycle Magnet Power Supply

Figure 8 shows the load waveform for the HEB when it is delivering beam to the test beam area. Average power for the cycle is 2.8 MW.

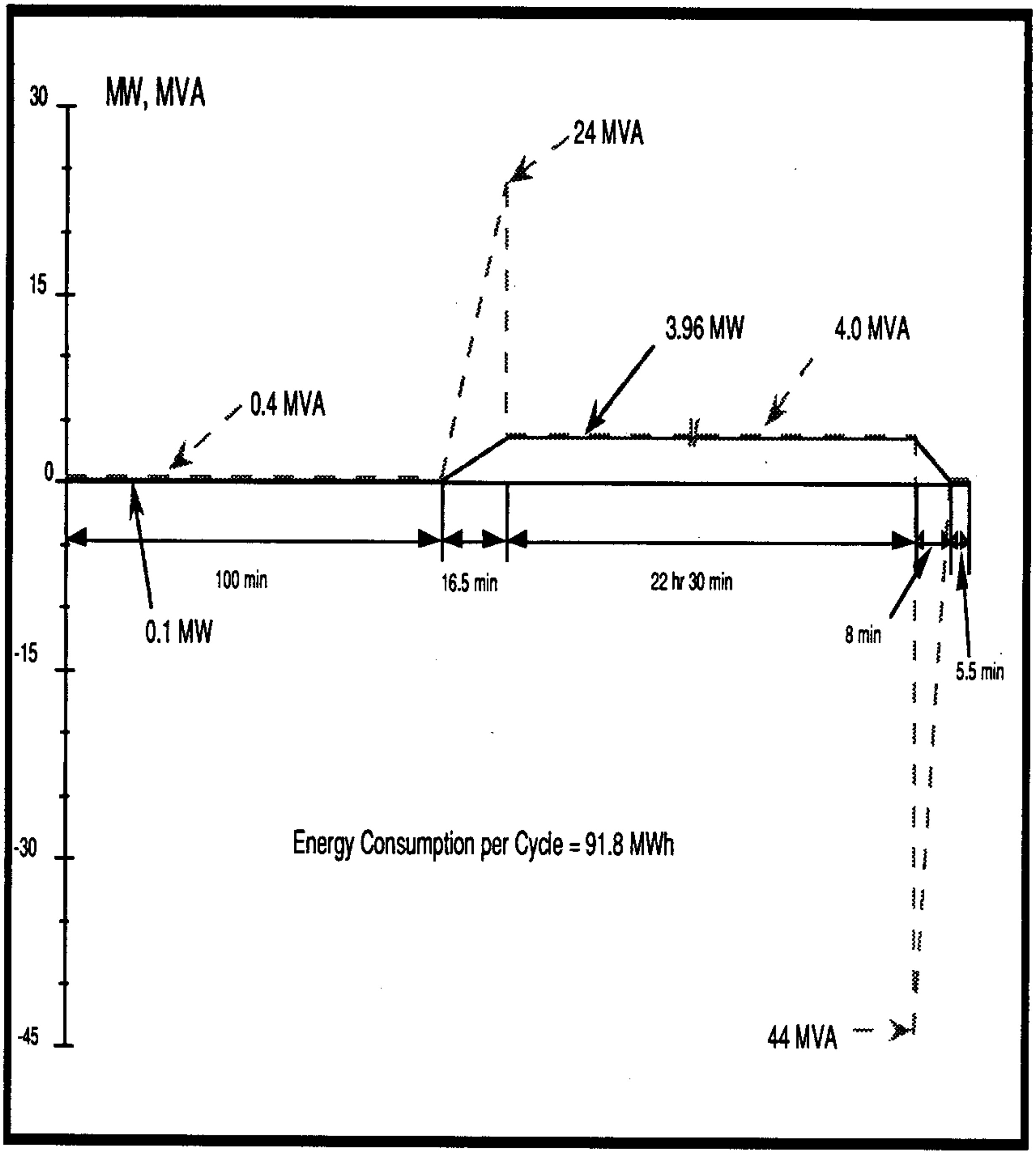

Figure 9. Collider Magnet Power Supply Load

Figure 9 shows the load waveforms for the Collider ramp. The MVA peak is greater on the down ramp because the rampdown is faster than the rampup by 8.5 minutes.

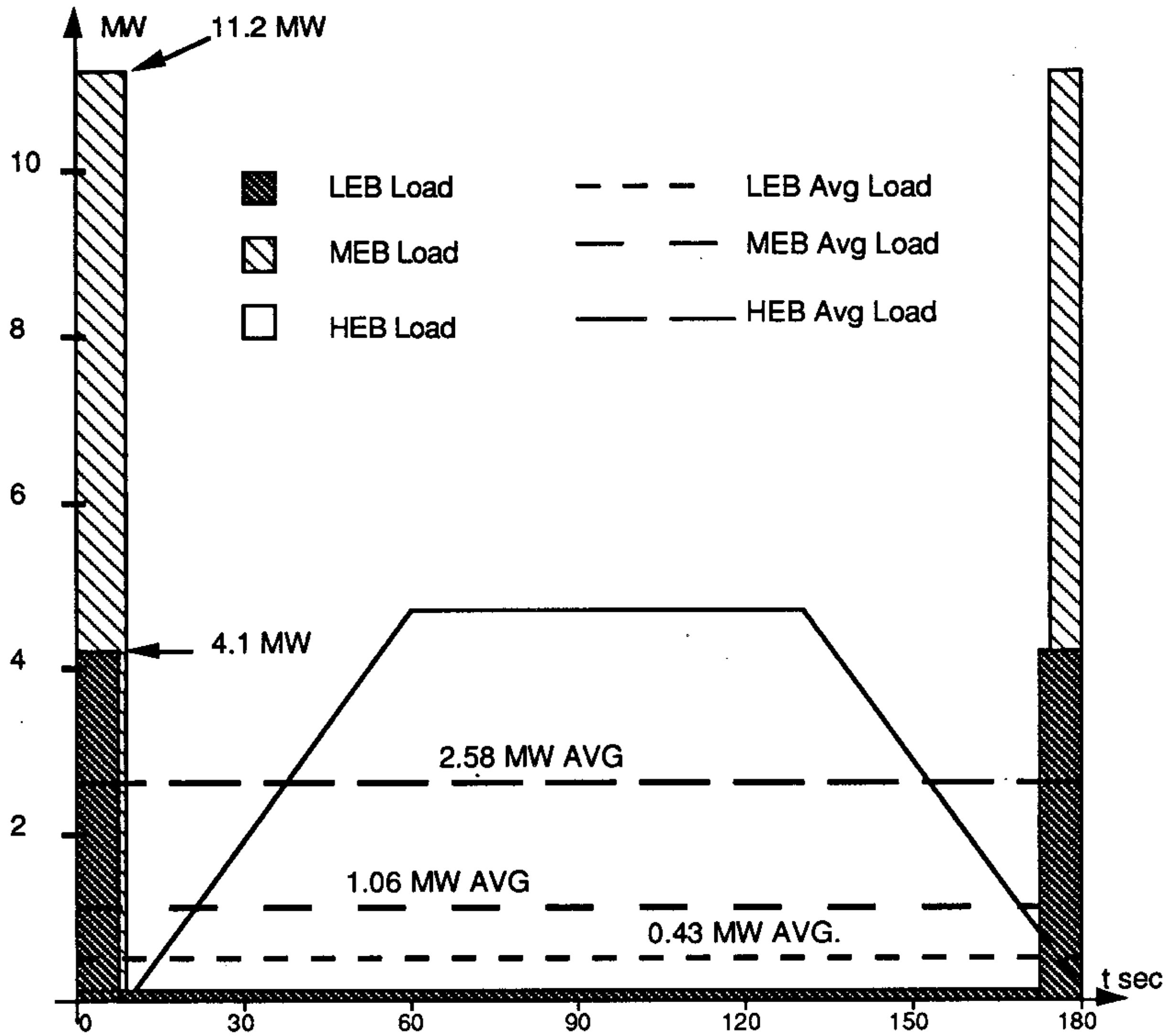

Figure 10. Injector Load Profile during Curtailment

Figure 10 shows the load profile for the injector during the load curtailment for test beam operation.

Summary

As indicated by the preceding tables and figures, the typical operating cycle described above offers many opportunities for substantial savings in power consumption, while imposing relatively few restrictions on the actual operation of the Collider. Prudent design and management of the major technical loads can be expected to reduce not only the operating cost of the SSC, but also the installed cost of the power system required to serve it. Further, use of the relatively simple load management techniques described above should improve both the reliability and longevity of the power supply system. While it is realized that the inherent experimental nature of the SSC will necessitate deviations from and variations on the cycle, these should be evaluated with their effect upon the power supply system in mind.