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Power Economies For the Fermilab Energy Doubler/Saver

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The many discussions that have occurred about potential power economies realizable with the Fermilab Energy Doubler/Saver are complicated by the multiplicity of variables that determine efficient operation of the power supply system. The following information has been assembled to provide a common basis for discussion of power economies possible when operating at energies of 400, 500, 800 and 1000 GeV. Several somewhat arbitrary but reasonable assumptions have been made in order to arrive at the standard operating modes; however, these should not be taken as necessarily representing limits on performance.

The maximum ramp rate that current Energy Doubler/Saver magnets are capable of exceeds 100 GeV/sec in most cases. However, the heat load generated by ac losses in the superconducting cable rises rapidly with ramp rate as does the L di/dt excitation voltage required to drive current through the magnet. Consequently, somewhat restricted rise and fall rates of 50 GeV/sec have been assumed. These are realizable with all recent prototype magnets.

Selection of flattop values is important because the longer the flattop the better the duty factor and the greater the power savings. This factor more than any other determines how much physics can be bought per dollar. There is of course no limit on flattop duration imposed by the superconducting magnet system. The restriction invoked here involves the capability of an extraction system similar to the one now installed in the Main Ring to provide beam spill of acceptable quality for long duration. Again selecting a conservative value, it is estimated that the present system could provide adequate beam spill over a 10 second flattop.* We have selected two cases for the Doubler/Saver: the 2 second flattop provides a more direct comparison to cases possible with conventional magnets at 400 and 500 GeV, and the 10 second spill, not possible with the conventional magnets at 400 and 500 GeV, was selected because it appears feasible and gives some idea of the effects on power economy of extended flattop duration. The feasibility of a 10 second spill can in fact be evaluated with present Main Ring systems. The power supply system can sustain a 10 second flattop at 200 GeV, requiring a 14 second total cycle and using 35 MW of average power and 40 MVA of RMS power.

Selection of an appropriate injection energy for the Doubler/Saver is fairly complex. With the constraint of a relatively slow superconducting magnet ramp rate, one wants to take advantage of the faster rise rate of the Main Ring to reach as high an energy as fast as possible. Power costs associated with higher energy operation must then be traded against acceptable overall duty factors in selecting an injection energy. This can be complicated by a dual operating mode wherein the Main Ring would be operated for one cycle as the Doubler/Saver injector and then for one or more cycles as an independent accelerator within each Doubler/Saver cycle. The optimum injection energy would appear to lie between 250 and 325 GeV. We have assumed a value of 300 GeV for injection into the Doubler/Saver and single mode operation of the Main Ring. While further study would probably produce a more optimum value of injection energy, 300 GeV should be close enough to that optimum for the present study.

With these major assumptions Tables I through V were prepared. The 70 and 100 MVA values shown for RMS power in Table I are the practical limits for the system configurations shown and include the substation transformers, feeder lines and Service Building transformer limitations. By "Present Main Ring" is meant the system as operating on May 14, 1975, without transformer 82A, the third Main Substation transformer. An "upgraded" Main Ring has improvements that will be installed within 6 months to one

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*H.Edwards and H.E.Fisk, Private communication.

year, including a new pulsed power transformer and additional RF to sustain 150 GeV/sec operation. The cases shown with 10 second flattops in Table III and V have not been presented in previous publications and are not even approachable with the present Main Ring system at energies above 300 GeV. The 7 MW of average power shown in Tables I through V for the Energy Doubler/Saver represents installed compressor power required for liquid helium refrigeration. There is enough flywheel effect in the refrigeration system that the 7 MW value should be constant over the range of duty factors shown. The only component of the heat load that depends on cycle time is the ac loss in the superconducting wire generated by ramping, and this is less than 20% of the total heat load.

In order to isolate the relative power requirements as much as possible to the systems affected, the dc power load associated with accelerator components other than Main Ring magnets and the Doubler/Saver is not included in Tables I to V. The 10.1 MW of power in this category will always be present with or without the Doubler/Saver. A list of the major subsystems and their contribution to the 10.1 MW dc load is given in Table VI. Power used by systems that are not part of the accelerator complex, such as experimental areas and the Village, have been omitted.

The data assembled here should provide a common basis for discussion of the Energy Doubler/Saver power economy question. Further refinements are of course possible and will be explored as the Energy Doubler/Saver design study progresses.

TABLE I

Power requirements for 400 and 500 GeV final proton energies using the Main Ring without the Energy Doubler/Saver.

Parameter	With Present Main Ring[1]	With Upgraded Main Ring	
Final Energy (Gev)	400	400	500
Rise Rate (GeV/sec)	100	150	150
Fall Rate (GeV/sec)	-300	-300	-300
Flattop (sec)	0.5	2	0.5
Period (sec)	15	7	12
Duty Factor (%)	3.3	28.6	4
RMS Power (MVA)	70	100	100
Average Power (MW)	32	80	50

1. Assumes only original Main Substation transformers and cables are available.

TABLE II

Power requirements for 400 and 500 GeV final proton energies with the Energy Doubler/Saver and a 2 second flattop.

Parameter	With Present Main Ring[1]		With Planned Main Ring Upgrading		
Doubler/Saver					
Final Energy (GeV)	400	500[2]	400	400	500
Rise Rate (GeV/sec)	50	50	50	50	50
Fall Rate (GeV/sec)	50	50	50	50	50
Flattop (sec)	2	2	2	2	2
Period (sec)	6	10	7	6	10
Duty Factor (%)	33	20	29	33	20
Average Power (MW)	7	7	7	7	7
Main Ring					
Inject to Doubler (GeV)	300	300	275	300	300
Rise Rate (GeV/sec)	100	100	150	150	150
Fall Rate (GeV/sec)	-300	-300	-300	-300	-300
Flattop (sec)	0.1	0.1	0.1	0.1	0.1
RMS Power (MVA)	38	29	25	31	24
Average Power	22	13	12	17	10
Total Av. Power (MW)	29	20	19	24	17
Ratio to Power for Main Ring from Table I	.36	Note [3]	.24	.30	.34[4]

1. Assumes only original Main Substation transformers and cable are available.
2. This mode not possible without the third Main Substation transformer.
3. No equivalent value available.
4. Table I flattop 0.5 sec.

TABLE III

Power requirements for 400 and 500 GeV final proton energies with the Energy Doubler/Saver and a 10 second flattop.

Parameter	With Present Main Ring[1]		With Planned Main Ring Upgrading	
Doubler/Saver				
Final Energy (GeV)	400	500[2]	400	500
Rise Rate (GeV/sec)	50	50	50	50
Fall Rate (GeV/sec)	50	50	50	50
Flattop (sec)	10	10	10	10
Period (sec)	14	18	14	18
Duty Factor (%)	71.6	56	71.6	56
Average Power (MW)	7	7	7	7
Main Ring				
Inject to Doubler (GeV)	300	300	300	300
Rise Rate (GeV/sec)	100	100	150	150
Fall Rate (GeV/sec)	-300	-300	-300	-300
Flattop (sec)	0.1	0.1	0.1	0.1
RMS Power (MVA)	25	22	20	18
Average Power (MW)	9.4	7.3	7.3	5.6
Total Av. Power (MW)	16.3	14.2	14.1	12.6
Ratio to Power for Main Ring from Table I	.51	Note [3]	.18	.25[4]

1. Assumes only original Main Substation transformers and cable are available.

2. This mode not possible without the third Main Substation transformer.

3. No equivalent value available.

4. Table I flattop 0.5 sec.

TABLE IV

Power requirements for 800 and 1000 GeV final proton energies with the Energy Doubler/Saver and a 2 second flattop.

Parameter	With Present Main Ring[1]		With Planned Main Ring Upgrading	
Doubler/Saver				
Final Energy (GeV)	800	1000	800	1000
Rise Rate (GeV/sec)	50	50	50	50
Fall Rate (GeV/sec)	-50	-50	-50	-50
Flattop (sec)	2	2	2	2
Period (sec)	22	30	22	30
Duty Factor (%)	9	7	9	7
Average Power (MW)	7	7	7	7
Main Ring				
Inject to Doubler (GeV)	300	300	300	300
Rise Rate (GeV/sec)	100	100	150	150
Fall Rate (GeV/sec)	-300	-300	-300	-300
Flattop (sec)	0.1	0.1	0.1	0.1
RMS Power (MVA)	20	17	16	14
Average Power (MW)	6	4.4	4.6	3.4
Total Av. Power (MW)	13	11.4	11.6	10.4

1. Assumes only original Main Substation transformers and cable are available.

TABLE V

Power requirements for 800 and 1000 GeV final proton energies with the Energy Doubler/Saver and a 10 second flattop.

Parameter	With Present Main Ring[1]		With Planned Main Ring Upgrading	
Doubler/Saver				
Final Energy (GeV)	800	1000	800	1000
Rise Rate (GeV/sec)	50	50	50	50
Fall Rate (GeV/sec)	-50	-50	-50	-50
Flattop (sec)	10	10	10	10
Period (sec)	30	38	30	38
Duty Factor (%)	33	26	33	26
Average Power (MW)	7	7	7	7
Main Ring				
Inject to Doubler (GeV)	300	300	300	300
Rise Rate (GeV/sec)	100	100	150	150
Fall Rate (GeV/sec)	-300	-300	-300	-300
Flattop (sec)	0.1	0.1	0.1	0.1
RMS Power (MVA)	17	15	14	12
Average Power (MW)	4.4	3.5	3.4	2.7
Total Av. Power (MW)	11.4	10.5	10.4	9.7

1. Assumes only original Main Substation transformers and cable are available.

TABLE VI

Breakdown of power requirements for accelerator components other than the Main Ring. The total 10.1 MW average power represents a constant load independent of Main Ring operations.

Linear and preaccelerator	1.6 MW
Booster Accelerator	2.2
Main Ring RF	.9
Main Ring Support Systems	3.9
Cross Gallery Systems	.2
Beam Transfer and Switchyard	1.3
TOTAL	10.1 MW