Accelerator Energy Conservation at Fermilab

James P. Morgan
Fermi National Accelerator Laboratory*
P.O. Box 500
Batavia, IL 60510

Abstract

The Fermilab Accelerator Division has adopted an energy conservation plan in an attempt to reduce power levels during extended periods of beam downtime. The plan was implemented for the first time during the 1990 Fixed Target program. In this paper I will describe how accelerator power levels are reduced, and attempt to assess the impact of the plan on accelerator operations and energy consumption.

1 Introduction

The Fermi National Accelerator Laboratory is a large consumer of electrical power, using about as much as a moderate sized town. During periods of High Energy Physics (H.E.P.), the accelerators and related support equipment consume more than half of the site-wide power. There are periods of time when component failure causes a disruption in the Physics program. It is possible to conserve energy during these periods of beam downtime without adversely affecting machine dependability.

Although the Accelerator Operations group strives to provide steady beam during Physics runs, there are inevitably periods when the beam is interrupted by equipment failures. In the past, the main power supplies for the various accelerators would continue to run, despite the fact that there was no beam to accelerate. The 1990 Fixed Target run had the highest reliability of the Tevatron era, but still had over 1,000 hours of downtime. During past Physics runs, there were often unneeded Main Ring Cycles occuring that are now removed. The Accelerator Operations group began to informally investigate the possibility of reducing power levels during periods of beam downtime in 1987. Initial results were encouraging, but a formal plan was not created until the Department of Energy offered incentives for energy reduction ideas. During the Fixed Target program in 1990, the first formal accelerator energy conservation plan was put into effect.

2 Modes of Operation

2.1 Fixed Target

During Fixed Target operation, the particle beam actually travels through a series of five accelerators before being delivered to the experimental areas. A failure of any one of these machines will prevent beam from being available to the experimenters. The journey begins in the Preaccelerator, where H− ions are accelerated to 750 keV. The ions continue through the Linac, and exit with a kinetic energy of 200 MeV. The first circular accelerator is the Booster, which cycles at 15 Hz and has an extraction energy of 8 GeV. During injection into the Booster, the electrons are stripped from the Hydride ions, leaving protons. The 8 GeV protons are transported to the Main Ring, which was originally the final accelerator. It now serves as an injector for the Tevatron and it takes 3 seconds to accelerate beam to the Tevatron injection energy. The Tevatron accepts 150 GeV protons from the Main Ring and accelerates them to 800 GeV. The Tevatron cycle repeats every 57 seconds. The particles are resonantly extracted to the experimental areas through a system of transport lines and splitting stations known as the Switchyard.

2.2 Colliding Beams

Unlike Fixed Target operation, where the particle beam is extracted from the Tevatron, proton and antiproton beams are stored for long periods of time in the Tevatron during Colliding Beams. The"stores" may last for more than a day barring equipment failure. While data is being taken at the experimental facilities, the other accelerators are used to provide beam for antiproton production. The particle beam follows the same path through the Preaccelerator, Linac, Booster and Main Ring, though the final energy for "Pbar stacking" is 120 GeV. The 120 Gev protons are extracted from the Main Ring and strike a Copper target. Among the resultant secondaries are antiprotons of approximately 8 Gev which are directed to a Debuncher ring for reduction of momentum spread and emittance, then to the Accumulator ring for storage. When a new store is initiated, antiprotons are extracted from the Accumulator, then accelerated in the Main Ring

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	Fixed Target	*Collider*	*Shut down*
Linac	2.0	2.0	1.2
Booster	2.5	2.5	0.8
Main Ring	3.5	5.0	0
Tevatron	3.0	1.5	0
Cryogenics	11.5	10.5	1.0
Swyd./8-Gev.	1.7	0.9	0.3
Util./Misc.	10.3	12.1	6.7
Accel. Total	34.5	34.5	10.0
Exper. Areas	17.0	6.5	3.5
Other	3.5	4.0	3.0
Site Total	55.0	45.0	16.5

Table 1: Typical Monthly Average Power Levels (MW)

before transfer to the Tevatron. The Tevatron accelerates the counter-rotating beams of protons and antiprotons to 900 Gev.

3 Site Power Consumption

Site-wide power consumption increases substantially during H.E.P. periods (see Table 1). In addition to the power used by the magnet power supplies and utilities, there is also considerable power use by the cryogenic system and experimental areas. A long list of smaller power supplies and support equipment also is energized during running periods. Site power useage is higher during Fixed Target Physics, but the difference is primarily due to increased power consumption in the experimental areas. Although Tevatron power use is lower in Collider mode, this is offset by an increase in Main Ring power. Linac and Booster power levels are the same in both modes of operation. During Fixed Target, the Switchyard transport lines are energized to deliver beam to the experimental areas. The Switchyard is not powered during Collider operation.

4 Description of Plan

The current energy conservation plan initiates the reduction of accelerator power levels in a way that won't delay the return of beam when the downtime ends. Also, during normal operation, the number of accelerator cycles is monitored, and any extraneous cycles are removed. This combination of trimming unneeded power use, and reducing power consumption during component failures is the nucleus of the plan. It is critical that power levels be reduced in an uncomplicated way and that the accelerators return to their normal mode of operation quickly.

After careful consideration, it was decided that the benefits from reducing Linac power was more than offset by potential difficulties. Potential power savings would be small, and reduction would not be able to be performed quickly or dependably. Similarly, it was decided that Booster power levels would be only reduced during lengthy periods of beam downtime. The main power supply for the Booster is the Gradient Magnet Power Supply (G.M.P.S.). Although there is a power reduction of about 1 MW when G.M.P.S. is turned off, there is a small loss in transmission efficiency due to thermal effects when the supply is first powered up. This problem can be mitigated by powering up GMPS a few minutes before the down period is expected to end.

The Main Ring and Tevatron provide the best opportunities for conserving accelerator energy at Fermilab. For periods of downtime anticipated to be less than an hour, the duty cycle of the Main Ring is reduced substantially. In this way magnet temperatures do not drop drastically, and power supplies and the R.F. continue to be periodically exercised. For periods of downtime anticipated to last a number of hours, the Main Ring ramp is turned off totally. The Tevatron is normally held at the "reset energy" of 90 Gev during down periods. Running at this low energy, and D.C., the power supply output and cryogenic demands are very small. Both rings can be brought back to the normal running mode in a minute or two. By reducing the Main Ring ramps and placing the Tevatron into a low energy store, power levels for the two machines are typically reduced from about 6.5 MW to 1 MW. In addition, there is savings from the reduced demand on the refrigeration system.

During Fixed Target operation, the Switchyard is used to transport beam to the experimental areas. During the Tevatron cycle, the majority of the Switchyard magnets are ramped up, and held at high field during the extraction process, which takes about 20 seconds. It is possible to prevent the magnets from ramping by withholding the ramp trigger. An automated system was developed that temporarily disables the trigger on cycles when no beam is present in the Main Ring and Tevatron. The Experimental Areas are also provided with a trigger at the same time to reduce power levels in their beamlines. When the Switchyard does not ramp, the power consumption is reduced by 1.2 MW.

5 Operational Experience

Results from the 1990 Fixed Target run have been very encouraging. After a short period of experimentation early in the Physics run, the mechanics of reducing power were worked out in such a way that machine reliability was not adversely affected. Because of the concern about cycling power supplies, energy levels were normally reduced by decreasing duty cycles.

To reduce Main Ring power, the number of ramps was reduced to two 120 GeV ramps every 57 second cycle. The operational configuration of ramps could quickly be returned when needed. This also reduced the amount of thermal changes that the magnets experienced. Typically, temperatures changed by small amounts, and returned to their previous levels within a few minutes of restoring

	Sitewide	*Accelerator*	*Exp. Areas*
1987 Collider	45.6	34.7	7.6
1987-88 Fixed Target	55.0 *53.1*	34.4 *32.5*	17.3
1988-89 Collider	44.5	34.0	6.2
1990 Fixed Target	55.0 *51.4*	34.8 *31.4*	16.9

Table 2: Average Power Levels (MW) *Pbar subtracted*

the normal ramp configuration. The Tevatron was put into a low energy D.C. mode to reduce power. To avoid problems with remnant field changes, the Tevatron was normally ramped a few times before beam was injected. Often the Main Ring and Tevatron could be returned to their operational state shortly before the downtime ended. Switchyard energy reduction was automated, and required minimal operator intervention. The only difficulty observed was that the Switchyard showed small beam position changes after the magnets had not been powered for approximately an hour or more.

6 Power Saved

At first glance, a look at the raw power data from the past two Fixed Target runs is somewhat discouraging. Average power levels for the Site were approximately the same. The accelerator related energy use showed a small increase, and the Experimental Areas showed a small decrease (see table 2). However, there were several notable differences between the two Fixed Target programs that mask the success of the energy conservation program. The large decrease in component failure during the most recent run is the most significant difference. During Tevatron magnet changes, the accelerators and beamlines are turned off for up to 5 days. The numerous magnet replacements caused the average site power for the run to be artificially low. Also, there was an experiment added to the Antiproton (Pbar) source for the 1990 program. This required power for the Pbar rings, as well as additional Main Ring cycles used to accumulate antiprotons. Table 2 reflects the net site and Accelerator power levels for the two runs when Pbar power levels are disregarded.

The 1990 Fixed Target run saw a dramatic reduction in downtime over the previous run (see table 3). A large percentage of the downtime that occured during the 1987-88 Fixed Target run was due to Tevatron magnet failures. A program of magnet maintenance and repair between the two runs drastically reduced the number of failures. This (happily) resulted in fewer opportunities to conserve power then expected.

It is relatively easy to account for the differences in power use due to the Pbar experiment. The Pbar power levels were calculated for both running periods and subtracted from the accelerator total. Records exist which indicated approximately how many Main Ring cycles were required for Pbar production. After the data has been corrected in this way, a reduction in accelerator power use is apparent.

	Fixed Target 1987–88	*Fixed Target 1990*
H.E.P.	2,872	3,205
Studies	619	344
"Up" Time	3,491	3,549
Failure	2,047	1,225
Start–Up	181	98
Total	5,719	4,872

Table 3: Machine Reliability (Hours)

It is more difficult to normalize the power data to the dependability of the accelerators. It is clear that the average power for the 1987–88 Fixed Target run would have been significantly higher if it wasn't for the large amount of downtime. Using data from Table 2, the accelerators were engaged in H.E.P. or studies 61% of the time in the 1987-88 run, and 73% of the time in the 1990 run. Two methods were used in an attempt estimate the energy saved. In the first, monthly data was compared from the two runs that had approximately the same amount of downtime. This involved taking the best months from the 1987–88 run and comparing them to the worst months from the 1990 run. The second involved extrapolating data from the 1987–88 run to match the 1990 run. Although both methods are imperfect and highly subjective, they both arrived at an energy reduction of about 3 MW for accelerator related power. The Switchyard contribution was a 7% reduction in ramps, which amounts to only .1 MW. This would suggest that experimental areas beamlines realized an average power reduction of up to .7 MW (they use 8–10 MW when running). When integrated over the entire 29 week Fixed Target run, this would amount to 14,600 MW–Hr saved by the accelerator division, and 3,400 MW–Hr by the Experimental Areas.

7 Conclusion

The Accelerator Division conservation program was success during the most recent Physics run. A substantial amount of energy was saved with minimal impact on machine reliability. Future efforts will be directed towards automating energy reduction.

References

[1] *Fermilab Accelerator Statistics*

[2] *Fermilab Master Sub-Station Monthly Energy Report*

[3] James P. Morgan. *An Energy Conservation Proposal*