ENERGY MANAGEMENT AT THE BEVALAC*

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Abstract

With the assistance of the DOE In-house Energy Management Program, various Bevalac electromechanical systems have been either redesigned, rebuilt, or retrofitted in the last several years in order to reduce both energy consumption and operating costs. Several more which have potential to save energy are under study and will be submitted to this program in the near future. Upgraded systems include RF amplifiers, dipole and quadrupole magnets, power supplies, and control systems for conventional facilities. Brief descriptions of these projects are given.

Introduction

Although the Bevalac still enjoys today a unique role as the only accelerator in the world capable of delivering beams of any atomic species in the 1 to 2 GeV/amu energy range, it performs this feat with hardware that for the most part is anything but modern. Both the SuperHILAC and the Bevatron were built and first operated in the 1950's, and although many upgrade programs have enhanced the capabilities of these accelerators, their basic operating sub-systems have remained virtually unchanged over the years. These accelerators were designed in a time when power costs were not nearly the factor they are today, and when achieving the required technical specifications required utilization of power-intensive technologies. In short, there are many excellent opportunities for modernization projects at the Bevalac which can yield great dividends in energy conservation.

Over the last several years a total of seven projects directed at process energy conservation at the Bevalac have been funded by the Department of Energy In-house Energy Management Program. These projects, listed in Table 1, all have paybacks in energy savings of three years or less, and contribute to about a 25% reduction in the electrical power used at the Bevalac, or a savings of almost half a million dollars per year. The projects are concentrated mainly in the linac RF systems and the external beam lines.

Table 1: List of IHEM Projects at the Bevalac

- SuperHILAC RF Power Amplifier System
- Pole Caps for Experimental Area Dipole Magnet
- Pole Caps for Experimental Area Quadrupole Magnets
- Beamline Power On/Off Control
- Bevalac Injector RF Amplifier Plate Modulator Removal
- SuperHILAC RF Power Supply Rectifier Upgrade
- Bevalac Magnet Cooling Fan Variable Speed Control

It is interesting to note that the Bevatron itself is actually quite efficient in its power usage. Although it is a weak-focusing accelerator, and hence has a huge beam aperture and tremendous stored-energy requirements (about 0.1 giga-joules maximum), this energy is supplied by (and returned to) flywheels in the motor-generator sets powering the main magnets. Power consumption is due, thus, to windage and friction in the MG sets and to resistive losses in the power system. As the Bevatron is air-cooled, the current density in the main coil is quite low (maximum of 120 A/cm^2), so resistive losses in the magnet coil are not high. In fact, under many operating conditions the largest power consumer in the Bevalac is the experimental beam area.

SuperHILAC RF Power System

In 1983 a project was begun to replace the ten RCA 6949-based 70 MHz high power amplifiers at the SuperHILAC with new units using the EIMAC 8973 tetrode. In addition to providing higher reliability and efficiency of operation, this tube was capable of holding off the full plate voltage with grid bias. This allowed for the removal of the series plate modulator circuits employed with the old RCA tubes. Elimination of the modulators was calculated to save almost $250K per year in power costs, arising from filament excitation and from voltage drop during the pulse. In addition, very significant savings would come from elimination of the need for maintenance of the modulator units, which had been notoriously unreliable in the recent past. A critical need for the new system was the design of crowbar circuitry to protect components under fault conditions. This project was fully reported in the last Accelerator Conference by Fugitt et al (1). Experience over the last two years has been excellent, the system has performed flawlessly, and the calculated power savings have in fact been realized.

Pole Caps for Experimental Area Dipole and Quadrupole Magnets

The Bevalac Experimental Particle Beam (EPB) area, shown in Figure 1, consists of a switchyard with three main channels leading to 8 different experimental stations. The present configuration uses 30 dipole and 48 quadrupole magnets in these beam lines, with several more magnets being included in experimental setups themselves. The magnets used have, for the most part, gaps quite a bit larger than required. Many of these magnets were used in the past for the transport of secondary beams, where large emittance and energy spread of the beams emanating from production targets dictated large beam channels for suitable acceptance.

Two projects were identified where reduction in magnet gaps could effect very significant savings in power costs. The first dealt with the large dipole magnet known as B39-M4, a 60" diameter magnet originally built with a 12" gap. Even the vacuum tank for the beam installed in this magnet was less than 8" high; the remaining space represented magnetic field volume totally wasted. The simple expedient of adding 2" plates above and below the beam height have resulted in savings of over $40K per year in power costs.

The second project isolated ten quadrupole magnets with 12" bores which could be reduced to 8" bores dropping power consumption in the magnets (power goes as the square of the gap) by 60%, for an average power savings of about $10K per magnet per year. These quads include eight 48" long and two 24" long magnets located in B30, B26 and B43, and are now in the process of being converted.

The conversion process consists of disassembling the magnets (shown in Figure 2), and machining off the semi-hyperbolic polefaces to form flat surfaces on which to mount the new poletips. The new poletips are located on the surfaces by dowel pins and are held in place by long throughbolts from the outside of the magnet. Figure 2 shows an end view of one of the quadrupoles; the original poletips were flush with the 12.375" diameter opening visible in the drawing depicting the supports for the (12") beam-pipe. The new poletips are seen, with a clear aperture of 8.25" through the magnet.

The new poletips were designed with the aid of the POISSON code and are similar to ones LBL designed and built for the PEP injection lines at SLAC (2). Machining of stepped

* This work was supported by the Director, Office of Energy Research, Division of Nuclear Physics, Office of High Energy and Nuclear Physics, Nuclear Science Division; and by the Office of Management and Administration, Office of In-house Energy Management, U.S. Department of Energy under Contract No. DE-AC03-76SF00098.
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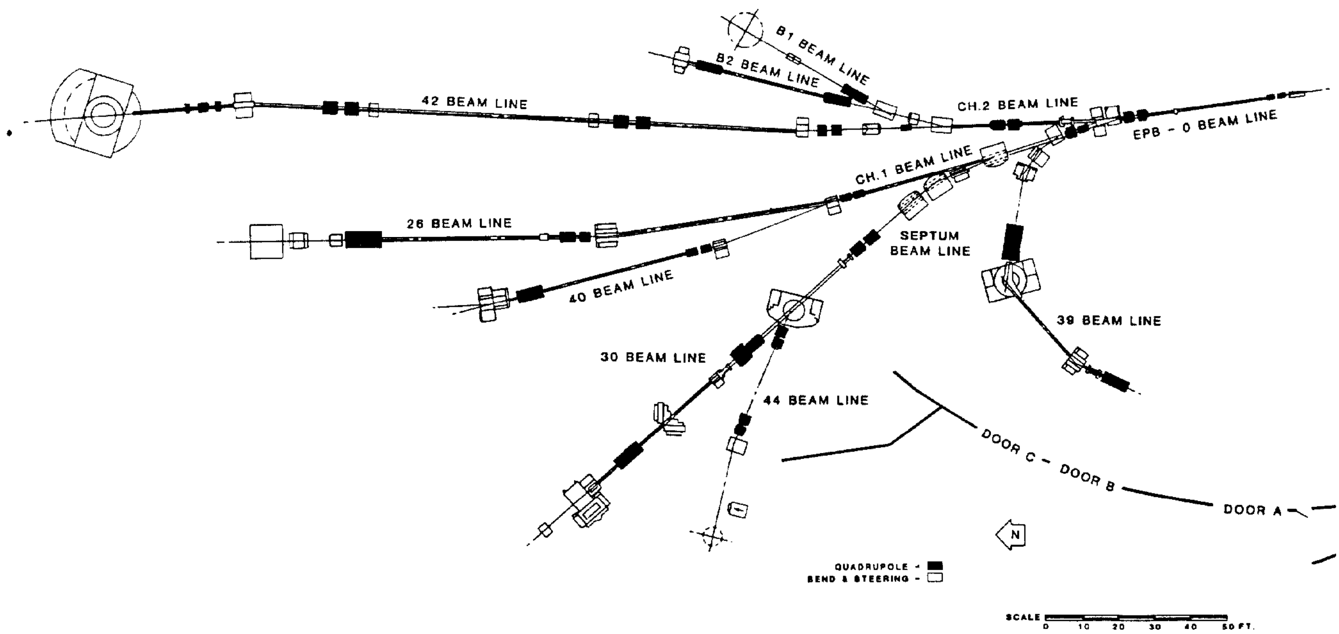

Figure 1. Bevalac experimental beam switchyard area.

poletips is considerably less expensive, and field quality at a reasonable distance from the poletip is quite good. Since typical beam envelopes only fill about three-quarters of the gap, the beam is entirely within the high field quality region of the magnets.

As a prudent first step, one 48" quadrupole was modified and tested for field quality prior to proceeding with the wholesale conversion. The results were entirely satisfactory; no single multipole error tested (multipoles through n=14 were measured) exceeded 0.5% under any possible operating condition within the six inch diameter envelope in which the beam is to be found. All errors were less than 0.2% under normal operating conditions. Most errors stayed well below 0.1% under all conditions.

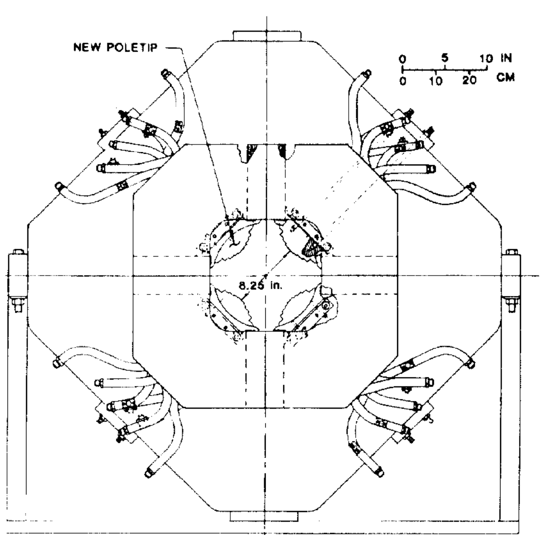

Figure 2. Schematic end view of modified quadrupole magnet. New stepped pole tips reduce magnet gap from 12.375" to 8.25".

At the present time four magnets have been completed, measured, and placed back in service. The remaining six will be installed before the start of FY88.

Note that the cost of this conversion (including engineering), about $28K per magnet, is less than half of the cost of design and fabrication of a new magnet with the desired polegap. The only disadvantage is the now excessive amount of steel in the return yokes, leading to a footprint for the modified magnet which is larger than that of a new magnet. In our application, these magnets were already in service, so space was not a problem.

Beamline Power On/Off Control

The highly flexible operating mode of the Bevalac typically requires exercising of several beam lines each week, some for testing and setup purposes in preparation for future runs. Monitoring and control of beam line status for many of the lines is still on a manual basis, resulting in the not-infrequent occurrence of leaving a line powered unnecessarily for many hours after a test is completed.

Since beam lines typically consume between 0.5 and 3.0 MW, it is obvious that very significant savings can be achieved by improving monitoring of beamline status. A project to implement this improved monitoring has been designed, with an estimated payback time of less than three years.

The project consists of the expansion of existing on/off control to all beamline power supplies, and the development of adequate software for deciding how and when to turn power supplies on or off as well as for presenting concise status information to operators. The hardware will be similar to existing hardware; software development and operator displays will use Sun workstations, in keeping with on-going plans for upgrading the present Bevalac computer control system. This project is now nearing completion, full commissioning is expected by the end of FY87.

Bevalac Injector Linac RF Plate Modulator Removal

Following on the heels of the highly successful modulator elimination in the SuperHILAC, a similar project, shown schematically in Figure 3, has been developed for the Bevatron Local Injector. This injector, which runs concurrently with the

SuperHILAC, produces the light-ion beams primarily used in radiotherapy (3).

The Thomson-CSF 515 and 516 tubes used in the 200 MHz final amplifiers are capable of standing off the full plate voltage, but mechanical details of the grid circuits must be modified for proper grid isolation from ground while still maintaining a good rf ground. Also, grid bias modulators must be designed and installed. As with the SuperHILAC, design of protection crowbar circuitry is of critical importance.

Although not as spectacular as the savings at the SuperHILAC, the project still will save about $25K per year in power costs, and will show about a three year payback. The modulator for the Local Injector has been a very high-maintenance sub-system, causing substantial down-time over the last years. Elimination of this item is expected to significantly improve reliability of the Local Injector. Project completion is scheduled for Summer of 1987.

SuperHILAC RF Power Supply Rectifier Upgrade

Additional modernization in the SuperHILAC RF system can yield still more power savings. A project for replacing the mercury vapor firing circuits used for the main ignitron rectifiers has been funded, with a projected savings of about $50K per year and a three year payback. The new system, consisting of solid state commercial firing circuits and custom impedance matching devices, will be able to regulate the output voltage as well as turn the rectifiers on and off. Power savings result from reduction of the required transformer series secondary resistors and capacitor surge-limiting resistors. This project, too, will be completed this summer.

Bevalac Main Magnet Cooling Fan Variable Speed Control

The Bevatron main magnet is air cooled, and uses two large fans to circulate the required amount of air. It has been found that maintaining the magnet temperature within a fairly narrow range (between 19° and 42°C) is of critical importance for preserving vacuum integrity in the Bevatron. Wide temperature fluctuations stress both the vacuum skins and the thirty-year-old, hopelessly inaccessible gaskets, inducing leaks which impact the accelerator vacuum. Because of operations at many different fields, cooling needs are highly variable. Each fan is driven by one of two motors mounted on opposite ends of the fan-shaft, either a 40 horse induction motor or a 250 horse synchronous motor. Currently, magnet temperature is monitored manually, and fans are turned on and off as needed to maintain magnet temperature within the acceptable range. A project is now nearing completion to allow for variable speed control of the 40 horse motors via commercial SCR phase controllers, thus providing superior control over magnet temperature. Power savings are effected by providing only the cooling that is actually needed at any given operating field.

Summary

The Department of Energy's In-house Energy Management Program has provided extremely valuable assistance in improving the efficiency of operation of the Bevalac. The modernization and retrofitting projects described have contributed to reductions in our power bill of close to $500K per year. Other areas where further power savings can be effected are being studied for possible future projects.

Acknowledgements

We wish to acknowledge the assistance of Don Roth and Dale Sartor of the LBL Plant Engineering Department for their liaison and coordination during these projects between ourselves and the DOE-IHEM program offices.

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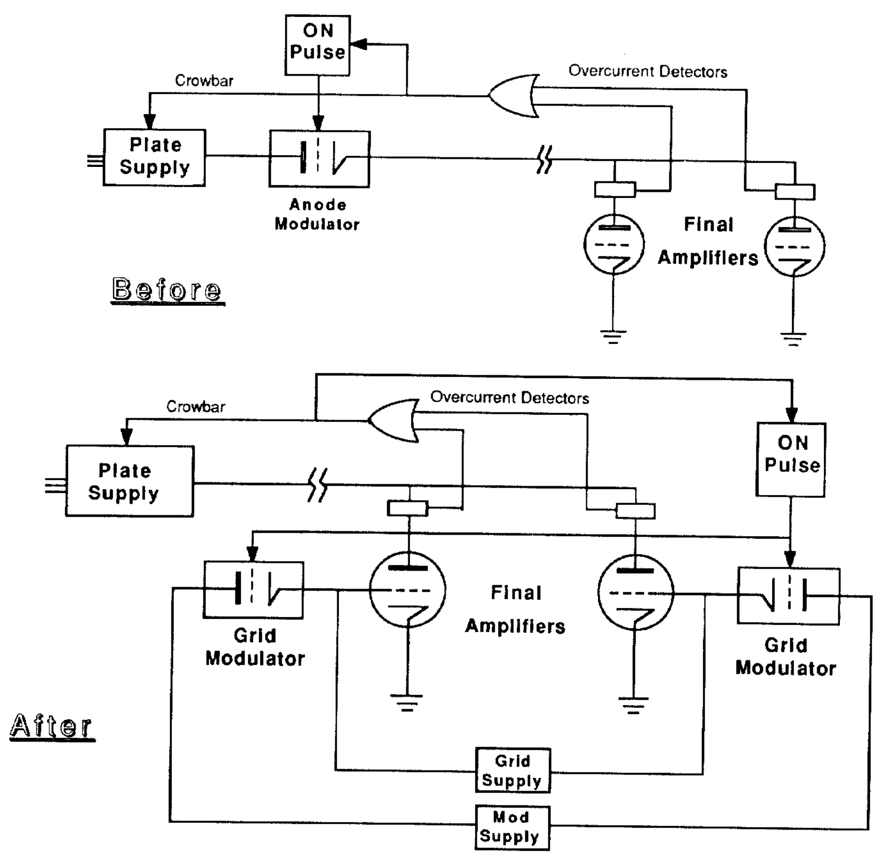

Figure 3. Simplified schematic of the pulse modulation systems for the SuperHILAC and Local Injector rf systems. Prior to upgrading pulsing was controlled by modulation of plate voltage. Significant power savings and operational reliability improvements result from replacing the plate modulator system with grid modulators.