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BATES LINAC OPERATIONAL EXPERIENCE*

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Summary

Accelerator operation during the first year of scheduled beam to physics experiments is described. Some details of the gun, RF, water, vacuum, control and monitoring systems are reviewed with reference to performance and reliability.

Introduction

The Bates Linac began regularly scheduled operation for intermediate energy physics experimentation during July 1974. Since that time there have been 1610 hours scheduled for operation. During 917 of these hours the beam was available to experimenters. Beam tuneup and operator training occupied 329 hours. For 364 hours the machine was down and undergoing repair. Beam-on hours for all purposes totaled about 1000 during this period. The accelerator beam parameters are chosen by experimental need and to optimize the quality and quantity of the data. The quality has in no case been limited by the accelerator. Only average current (for most experiments) and peak current (for one experiment) have limited data quality.

Operations

Average current is presently limited to about 25μA by the current-handling capabilities of the switchyard vacuum components (slits, collimators, seals). Most of the accelerator down time has been for repair of switchyard vacuum. The failures resulted from improper handling of high beam currents. Both the switchyard components and the switchyard beam diagnostics are now being improved. It is expected that the maximum operating current will be increased to 50μA within six months and to 75μA within a year. Energy requests from experimenters have ranged from 80 to 320 MeV and have all been met. Energy to 380 MeV has been available, although we are at the moment limited to about 340 MeV by a shortage of high voltage switchtubes.

There has been as yet no need for beam duty ratios in excess of about 0.4%, and normal running for much of the current program is at about this duty (14μs beam pulse width at 300 PRF). As average current capability is increased, duty ratio for the electron scattering program will increase proportionally. There is also a new experiment scheduled soon which may require a duty ratio approaching 2%. System tests have been made to 0.8% beam duty (1% RF duty), but there is not yet the experience to know whether beam stability and major component lifetimes are presently adequate for routine operation above 0.5%.

The beam quality requirement to date has been for energy definition of 0.3% and is met by fixing the width of a slit through which the beam must pass while dispersed in the switchyard. One can normally pass 90 to 100% of the accelerated beam through a 0.3% slit, but instabilities are such that the operator must keep hands-on for much of the time to maintain a steady beam under these conditions.

Controls

The accelerator was designed[1] to rely on individual component stability (through internal feedback or conservative specification) to achieve total system stability, rather than a computer-controlled, system-wide feedback scheme to compensate for drifts. However, at some point, individual component or sub-system stability becomes too expensive or impractical and the adjustment or setting of levels sequentially by hand becomes too slow or complicated for efficient operation. Thus, to allow for computer interfacing for monitoring and control, while keeping the initial control system inexpensive and simple for machine startup, analog and dc metering pulse signals are largely hard-wired into the central control room (a maximum distance of 300m) for switching and multiplexing at a single location. The desired readings are selected either thru bifurcated, crossbar contacts (which are switched by binary-code-addressed relay trees for DPM display) or by sample-and-hold circuits on the inputs of IC multiplexers for less accurate but simultaneous oscilloscope display. The controls ultimately provide power to motor-driven devices, variacs, or potentiometers, by activating 120Vac or +24Vdc trunk (bus) lines to which are tied T-bar relays and binary-code-addressed relay trees for routing to the desired remote motor. Most of the control motors are small, low current, geared ac or dc types that can be driven directly from the trunk line. The exceptions are relay driven from local sources.

Presently, all the machine settings are read out on two "primary" DPM's (one for the accelerator and one for the beam switchyard), a supplemental 7-digit DVM, a digital thermometer, a frequency counter, and up to five oscilloscopes. Assigned pushbuttons, serially-selected, allow rapid, simple, and largely trouble-free access to all machine settings and controls. The 0 to ± 2000mVdc metering signals in CCR are kept relatively free of noise and stable by using twisted, shielded wires from either low impedance series dropping resistors (0.01 to 1 ohm for the magnetic elements) or 10-turn, position-tracking potentiometers for RF phase shifters, power dividers, and some power supplies at high voltage. The 10-turn potentiometers are supplied from a local or remotely switched, LM309K-type, +5Vdc regulator connected to the +24Vdc house line, and the potentiometers produce fairly quiet CCR readings if limited to 100 or 200 ohms. A 60 Hz input filter on the DPM gets rid of any line frequency ground currents or pickup.

Interfacing a PDP 11/45 with the accelerator for the purpose of logging settings is scheduled and provisions have been made to computerize the setting of the beam switchyard quadrupoles and bending magnets with stepping motors for greater speed and flexibility in handling and analyzing the beam. In fact, any machine parameter could be set by the computer by controlling the existing binary-addressed relays and relay trees in accordance with a digital comparator-processed difference between the desired reading and the measured reading.

Systems Reliability Experience

The accelerator and beam switchyard steering coil power supplies and controls have given largely trouble-free service[2,3]. The ten General Radio 874-9002 RF phase shifters in front of the high power VA938 klystrons are motor-driven trombone air lines that have operated reliably and smoothly at peak powers of up to several hundred watts (tens of watts average). The UVC drive klystron power supplies and the 4K3SN-1 klystrons have been very reliable, too. The original complement of six 4K3SN-1's are still in service after over five years of existence and from 2000 to 6000 hours on the various tubes' filaments. It should be noted that most of the 6kV, 1kWcw tubes and the 8kVdc power supplies are operated close to 4kV and 200W of peak RF power out (the driveline is run pulsed at S-band). Also, the klystron heater is slightly underpowered (although still run space-charge-limited) to lengthen tube life. One tube is beginning to show signs of decreased gain and another high body current (~8%), but both tubes are still up to providing their required operational stability.

The original gun cathode is still "hot" five years after initial processing and with over 2400 hours of filament time in spite of one accidental let-down to a few Torr of air when the cathode was cold. There have been a few cases of blown light links and gun accelerating column resistors, but none since the gun tank SF_6 pressurization procedure has been improved in order to reduce the partial pressure of water vapor to much less than 0.1 Torr. Coincidental?

The one-half wavelength, rectangular, RF windows at the entrance of the rectangular waveguide networks initially caused considerable RF processing and cleaning problems, but they have cleared up, at least for up to 3.5 MW of peak RF power at over ½% duty cycle. There is no obvious explanation for our earlier difficulties, nor is there a satisfactory explanation as to why those difficulties disappeared, other than that a lot of in-service processing is necessary. There seems to be no discernible difference in processing our titanium-coated alumina windows and the uncoated ones.

The vacuum along the accelerator is generally very good. It is better than 10^{-8} Torr in the gun region and generally better than 10^{-7} Torr along the machine. The beam switchyard vacuum standards are not as high as those for the accelerator, and its vacuum pressure often above 10^{-6} Torr. Most of the accelerator vacuum pumps are still in service (since 1972 or before); three out of the ten RF window 25 l/s pumps have been replaced, and two out of the twenty-seven accelerator centerline 50 l/s pumps have been reworked.

All five RF transmitters[4] have been operated extensively at up to 0.6% duty ratio. For each of the first three transmitters total operating times exceed 3000 hours. During the past several months down time for minor repair and maintenance has been minimal. During the past year there have been two failures-in-service of high voltage switchtubes in which the damage was irreparable. The cause of these failures and ways of preventing such failure in the future are currently under study. Several switchtubes no longer have full specification voltage hold-off capability; thus the peak RF capability of the transmitters and the available accelerator energy is limited. A facility for switchtube voltage processing is under design. Other smaller problems have been encountered, such as the failure of circuit breakers on the high voltage deck under oil. Several diode rectifier stacks in several of the modulator 180kVdc power supply oil tanks have blown and caused an imbalanced load on the corresponding 480 Vac, 3Ø inductrols. In each case the modulator continued to work but the normal inductrol hum slowly increased to a growl, probably as a result of higher harmonics of 60Hz generated by the imbalanced loads. Twice, before the cause of the problem was understood and eliminated, the vibration became so bad that the inductrol rotor windings loosened to the point that they required re-epoxing to the rotor.

The accelerator water system has generally remained clean and temperature stable. There have been a few localized erosion problems discovered due to improperly high flow rates. The use of polyethylene-lined aluminum pipes for the main water headers has proved to be a worthwhile economy. However, a few pieces of plastic linings from the cast iron that connect the lined aluminum pipes have been found in the water system. More than half of the helium gas-bulb thermometers that are mounted inside of the accelerator section vacuum envelopes at a temperature fulcrum point[1] are now inoperative. At higher duty cycle operation remote and possibly automatic control of the accelerator section's input water temperature to duty-cycle-dependent values will be instrumented.

Beam Diagnostics

The procedure for getting the beam through the 12mm apertures at each accelerator section has been determined largely by experience with the help of some combination of the following beam position and peak current monitoring devices: 1) four Q cavity-type-current monitors in the injector, 2) eleven RF loads along the accelerator (for RF phasing by beam loading), 3) four NBS toroidal current pulse monitors in the beam switchyard and spectrometer room, 4) thirty radiation detectors distributed along the machine multiplexed and displayed on a single oscilloscope trace, 5) eight SLAC xyQ RF cavities, 6) beam dump current monitors at the various ends of the machine (injector, 0°, 14°, and $37\frac{1}{2}^\circ$ areas), 7) an insertable two-dimensional harp (secondary emission, xy, wire array), and 8) several insertable screens with TV viewing ports. With the exception of the harp, most of the above devices are standard and have been discussed by others elsewhere.

The harp consists of a triple-layered frame of G-10 fiberglas, printed circuit boards that can be rotated out of the beam line. The frames' outside dimensions are 10 x 10cm and the inside dimensions are 6 x 6cm. The assembled thickness of the frames is 6mm. There are nine 0.2mm diameter gold-plated tungsten wires per mm across the openings. On the vertically-sensing (horizontally wired) frame they are wired to the outside mostly in 3mm groups (27 wires), except at the extremities. On the horizontally-sensing (vertically wired) frame they are wired mostly in 1mm groups. In between the horizontal and vertical frames there is a shield frame with one wire per mm. The shield frame can be biased to reduce crosstalk from the horizontal to the vertical frame. Externally, each group of wires feeds a sample-and-hold circuit on the input of a 64-channel multiplexer (48 for horizontal and 16 for vertical). The multiplexer is swept every beam pulse and its output is displayed on an oscilloscope as a "bar-graph" of the beam current density in the x and y dimensions. The durability of the harp is yet to be demonstrated since the multiplexer electronics is being redesigned and has been unavailable for several months since the first tests. Most of the other above-mentioned monitors are available for viewing at the central control console. A pair of xy cavities, one at the end of the accelerator and one early in the beam switchyard, are regularly used as null devices for establishing the correct beam entrance conditions to the switchyard. The xyQ cavities along the accelerator have yet to be aligned for optimum steering conditions, so the radiation detectors now serve to alert the operator concerning where the thread of the beam is slipping out of the eyes of the accelerator collimator needles.

Future efforts will concentrate on improved modulator reliability, machine protection instrumentation for higher current operation, improved beam stability, and gradual computer interfacing for improved efficiency and stability.

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