SLAC-PUB-3615
March 1985
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COMMISSIONING AND OPERATION OF THE NUCLEAR PHYSICS INJECTOR AT SLAC*

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Abstract

The new Nuclear Physics Injector (NPI) approved for construction in October of 1983 was completed by September of 1984, and delivered short pulse beams for SPEAR ring check-out in mid-October. Long pulse beams of up to 1.6 microsecond length were also demonstrated. The paper describes the start-up operation, reviews the performance characteristics, and discusses the beam transport optics used to deliver 1 to 4 GeV beams to nuclear physics experiments in End Station A. The SLAC Nuclear Physics Injector is in full operation!

Why NPI?

How long should a linear accelerator be? One might expect the response from SLAC to be "the longer the better." This is clearly wrong. A better answer is, "long enough to reach the desired energy." The reason for this is that while the energy achievable increases with length, the maximum current within a given energy spread varies roughly inversely with the length. The reason for this is wake fields. Longitudinal wake fields, whose effects have traditionally been called beam loading, cause an energy transient for one filling time (.8 μsec at SLAC). The magnitude of the transient is proportional to the length of the linac and varies linearly with current but is independent of the number of accelerator sections which are actually being used to accelerate the beam. Thus the percentage energy spread produced varies inversely with the energy of the beam. The transient can be reduced by a factor of 10 to 30 by an appropriate distribution of times at which the klystrons are turned on.

Transverse, or dipole wake fields cause the phenomenon known as Beam Break Up (BBU) in which the transverse noise on the beam is amplified by induced fields in the accelerator structure until the trailing end of the beam is lost. The beam current threshold at which this occurs varies linearly with the energy of the beam and inversely with the length of the structure.

Description

To satisfy the needs of the nuclear physics community for high average currents in the energy range from 1 to 4 GeV at a minimum cost, the Nuclear Physics Injector[1] shown in Fig. 1 was installed 600 meters before the output of the 3000 m accelerator at SLAC. Conceptually the new injector is identical to the old injector built 20 years ago. Many engineering improvements have bean made, including a new electron gun, new gun electronics, and of course the new injector is controlled by the new SLAC Linear Collider computor control system. The new gun and gun electronics enable us to interlace 2 nsec pulses for filling the storage rings with 100 nsec to 4 μsec pulses from the same gun. The gun, Fig. 2, is mounted off the accelerator axis at an angle of 105° with respect to the accelerator axis. The beam is bent onto the accelerator axis by a pulsed α-magnet which bends the beam through 255° which causes the beam to describe a path similar to the Greek letter α. With this geometry the magnet acts as a magnetic mirror with the bend angle and the position of the outgoing beam being independent of the magnetic field in the magnet over a wide range. In practice the magnet field can be varied 25% with only a slight change in the transmission. This makes the magnet pulser stability very uncritical.

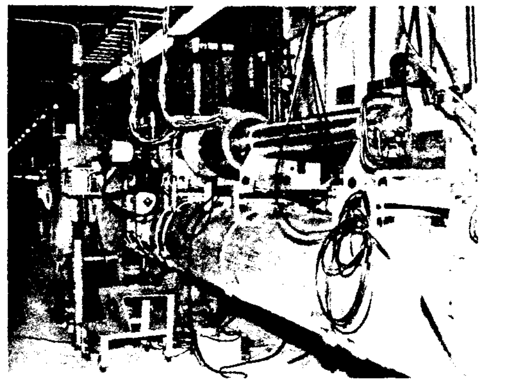

Fig. 1. The Nuclear Physics Injector (NPI).

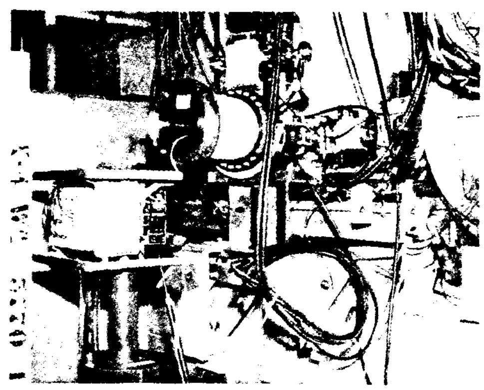

Fig. 2. The NPI Gun.

To provide room for the new injector, two of the four 3 m accelerator sections driven by klystron 25-1 were removed. A special 3.1 m injector structure was mounted roughly in the middle of the space made available. This section has a 3 m accelerator section and a separately powered 0.75 c traveling-wave buncher. Half the power from klystron 25-1 drives this section with power for the buncher provided from a 10 dB coupler in the waveguide to the injector accelerator section. Figure 3 is the SLC Control Computer graphics display of the Nuclear Physics Injector. The off-axis gun is indicated near the middle of the diagram. The beam passes through two magnetic

*Work supported by the Department of Energy, contract DE-AC03-76SF00515.

Poster paper presented at the 1985 Particle Accelerator Conference
Vancouver, B.C., Canada, May 13-16, 1985

lenses to the α-magnet. The beam is bent onto the accelerator axis by the α-magnet. It then passes through the buncher where it is velocity modulated to begin the bunching process. After a 25 cm drift it enters the buncher and then the 3 m accelerator section where it is accelerated to about 35 MeV.

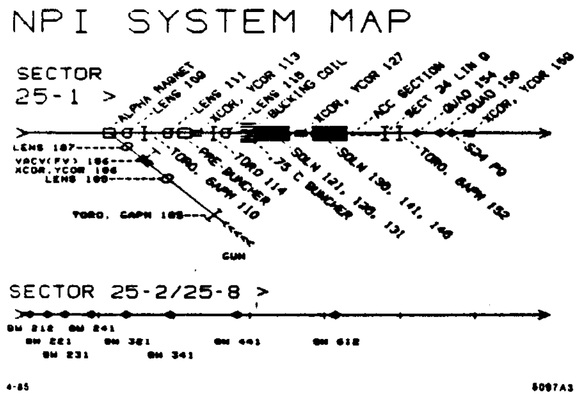

Fig. 3. Computer display of the NPI system showing the injector in Sector 25-1 and the special NPI quadrupole lattice in Sectors 25-2 through 25-8.

Focusing

Between the gun and the buncher the beam is focused by five magnetic solenoid thin lenses. In the buncher and accelerator the beam is focused by two 45 cm long solenoids: the first around the buncher and the beginning of the accelerator section and the second after about 1 m of acceleration. After the first accelerator section the beam is focused by eight quadrupoles mounted in a tapered FODO array around the next 60 M of the accelerator (QW212-QW612 in Fig. 3). The spacing of the quadrupoles increases linearly with the distance from the injector to form a constant admittance lattice as the energy increases. This tapered array matches into the standard SLAC lattice consisting of a pulsed quad doublet every 100 m.

Control System

The Nuclear Physics Injector runs under a control system that is designed for the SLAC Linear Collider (SLC). For a more detailed description of this system see Ref. 2. Operators interact with the control system through a console on wheels (COW) which consists of an 8 × 8 button touch panel, four general purpose slew knobs, a graphics display monitor and an Ann Arbor Ambassador terminal. Each COW has a multibus crate containing modules which allow it to generate graphics and to interface with the VAX host computer through SLC-NET. Since COWs and supporting software already exist for the SLC, no new control system development is needed for NPI.

The COW communicates with magnets, gun pulsers, klystrons and other devices through the SLC control program (SCP) which accesses three data structures; a database, a configuration set and the timing matrix (T-matrix). The database stores static information such as magnet polynomials for current versus field, operating limits and control connections, and quasi-static information such as the present current in magnets or the phase of klystrons. Configurations hold only quasi-static information about specific devices controlled by specific micros. The SCP allows operators to save and restore a recent lattice for a real or model-derived beam trajectory by micro and machine region. The T-matrix holds all of the timing information for the machine. No other data structure holds information on a pulsed basis. Each pulsed device is triggered by a programmable delay unit (PDU) which generates appropriately delayed timing pulses after receiving a fiducial. After receiving a fiducial from a coaxial drive-line and a beam code from a master pattern generator that indicates which beam is coming on the next pulse, the PDU determines timing by triggering the devices assigned to that beam with the delay recorded in its copy of the T-matrix. In the NPI system a PDU triggers four gun pulsers, an α-magnet and a klystron attenuator which provides an energy vernier.

Because NPI is 2400 m downstream of the main injectors, it can deliver beams to nuclear physics experiments at SLAC while the SLC upgrade continues. This was proven in January of 1985 when the NPI supplied electron beams to end station "A," the Stanford Synchrotron Radiation Laboratory and PEP while the first two-thirds of the linac remained open for SLC component installation, check-out and maintenance. This mode of operation will be put to use in the future for extended summer experiments. Running the NPI and 40 klystrons uses one-third of the electricity it takes to run the main injectors and the 128 klystrons required to make beams energetic enough to drift through the long middle of the linac, followed by deceleration to the proper low energy.

Check-out and Operations

The Nuclear Physics Injector was installed during the summer of 1984. In August a portion of the accelerator tunnel was

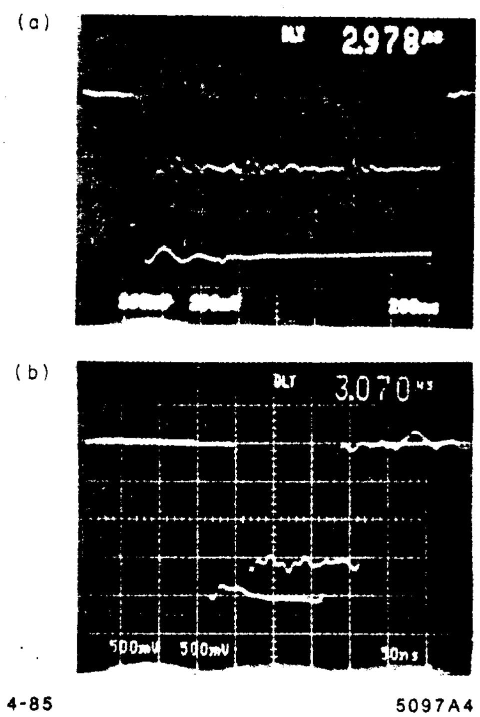

Fig. 4. a) NPI gun current and current at 35 MeV point. Vertical scale 100 mA/cm; horizontal 200 nsec/cm. b) Same signals with 780 mA accelerated. Vertical scale 250 mA/cm; horizontal 50 nsec/cm.

locked up and the RF system was checked out and the accelerator structure was processed to full power. Then the gun and gun electronics were installed. On September 6 the gun system was tested and pulsed at full current.

Since the beam switchyard and the rest of the linac were not scheduled to be available until early October, a short section of beam pipe had been removed and a temporary beam dump installed. The week of September 14 NPI was run for the first time. A maximum current of 780 mA was accelerated. Figure 4a shows the gun and accelerated (35 MeV) current pulses on a 100 mA/cm scale. In Fig. 4b the same signals are shown with higher currents on a 250 mA/cm scale.

On October 13, 1984, the first beam from NPI was delivered to the SPEAR storage ring. The gun current pulse for the SPEAR beam is shown in Fig. 5. This beam is seen on a fluorescent screen at SPEAR at the entrance to the storage ring in Fig. 6. The beam spot appears to be flat on one side because of a burned spot on the screen. NPI has been used continuously since then to provide electron beams for SPEAR.

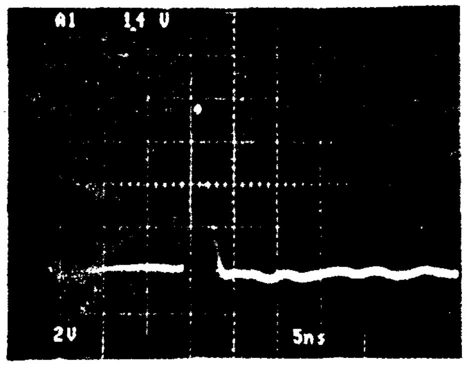

Fig. 5. NPI gun current pulse for SPEAR storage ring. Vertical ~ 250 mA/cm; horizontal 5 nsec/cm.

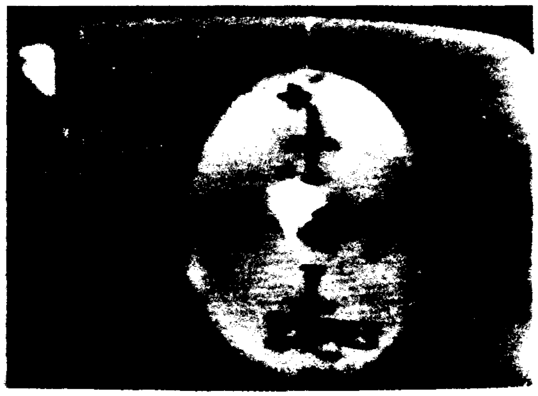

Fig. 6. SPEAR electron beam from NPI on profile monitor at entrance to storage ring. Beam spot appears flat on one side because of a burned spot on the screen.

In December the first operation of NPI for long-pulse high-current low-energy (1 to 3.5 GeV) was attempted. At first the current which could be obtained was limited by excessive beam loss after 100 m. The protection long ion chamber for the accelerator limited the peak current we could deliver to the experimental area to about 35 mA. During the 10-day shutdown for Christmas and New Years a 1 cm diameter collimator was installed right after the injector to scrape off beam halo. In addition, a new optics was developed which reduced the admittance of the first 25 m of acceleration so that halo would be scraped off at low energy. With these changes beam loss in the accelerator was no longer a problem.

During January the new injector performed very well for N.E.-3: the first nuclear physics experiment to run at SLAC. Beams were provided in the energy range from 2.5 to 3.5 GeV with typical currents of 25 to 50 mA, and pulse lengths of 1.4 to 1.5 μsec in a 0.75% FWHM energy spectrum. The highest current achieved was 67 mA averaged over a 1.6 μsec pulse.

Future Improvements

There are three significant changes remaining to be done which will improve the beam for nuclear physics at SLAC. Both of these are part of the linear collider improvements. The first, which will be implemented this summer, will give the operators control of the timing of each klystron on the accelerator. This will enable the NPI operator to correct very precisely for the beam loading energy transient by turning on individual klystrons late. Thus the operator will be able to prevent the energy from falling due to beam induced waves by turning on more klystrons progressively. For SLAC the smallest group of klystrons which can be timed remotely is eight. This is much too large an increment for the NPI beams. The second improvement will be changing the klystrons and klystron modulators to increase the RF pulse from 2.5 to 5.0 μsec. Since about 1 μsec of the RF pulse is lost due to the filling time, doubling the RF pulse width will increase the usable beam pulse from 1.5 μsec to 4 μsec. The last SLC modification which will help nuclear physics beams will be the installation of eight quads in each 100 m instead of the present two. This strengthens the focusing enough to raise the BBU threshold by a factor of 1.5 to 2. These three changes should make possible 100 mA pulses 4 μsec long at 120 pps as compared with the present 60 mA, 1.5 μsec at 180 pps. Thus average currents of 48 μA should be achievable. At present we can achieve about 16 μA.

Acknowledgements

The authors wish to acknowledge the outstanding effort by many on the SLAC staff which enabled the Nuclear Physics Injector to become operational several months ahead of schedule. Singling out a few of the many, we wish to thank C. Rago, R. Wooster and J. Morton for their mechanical design and installation work, D. Bostic and his vacuum crew, R. Walton and G. Jones for the I&C installation, J. Rolf and R. Ortiz for their work on the beam containment system, K. Underwood for software assistance, E. Ferandin, K. Johnston and the technical illustrations staff for producing this paper, A. Friedel for documentation, and finally and very important, T. Inman and all the control room operators for their enthusiastic and skillful tuning.

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