The 3 GeV Synchrotron Injector for SPEAR*

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Abstract

A dedicated 3 GeV injector synchrotron for the storage ring SPEAR has been constructed at the Stanford Synchrotron Radiation Laboratory, SSRL, and has become operational by November 1990. The injector consists of an rf-gun, a 120 MeV linear accelerator, a 3 GeV booster synchrotron and associated beam transport lines. General design features and special new developments for this injector are presented together with operational performance.

I. INTRODUCTION

The 3 GeV storage ring SPEAR is fully dedicated to the production of synchrotron radiation since 1990. To eliminate the need to fill SPEAR from the SLAC linear accelerator causing significant interruption of SLC operation SSRL proposed in 1987 to DOE to construct a 3 GeV full energy dedicated electron injector for SPEAR [1](Fig.1). This

Figure 1
3 GeV SPEAR injector

proposal was approved and construction begun in February of 1988. By mid of 1990 most component had been constructed and installed and commissioning begun. First beam tests to the booster started on July 20 with successful capture the same day. After a summer shut down to complete installation, first acceleration occurred on September 6 and beam was stored in SPEAR the first time from the new injector on November 21, 1990.

II. GENERAL INJECTOR FACILITY

A. Basic Design Goals

The basic goals for the design of all components was to produce an electron beam for injection into SPEAR with an energy of 3 GeV and an intensity which would allow to fill SPEAR to 100 ma in less than 5 minutes. The electron source is a 2.5 MeV rf-gun and after acceleration to 120 MeV in a linear accelerator the particles follow a short beam transport line to the booster synchrotron. The booster magnets are energized by a White circuit cycling at 10 Hz. After reaching the SPEAR injection energy the beam is kicked out of the booster into a beam transport line to SPEAR.

B. Parameters

The lattice of the booster synchrotron is based on a simple FODO structure of 20 cells. To accommodate the rf system, instrumentation and injection and ejection components a missing bending magnet scheme was employed without interrupting the FODO focusing. This scheme depresses the dispersion function at the bending magnet free sections where the rf cavity is installed. In Fig.2 the magnet structure and lattice functions are shown for one
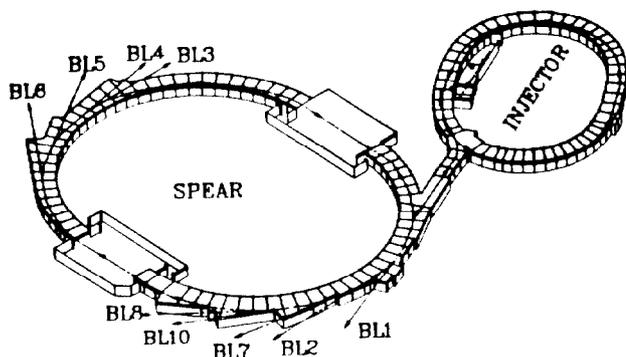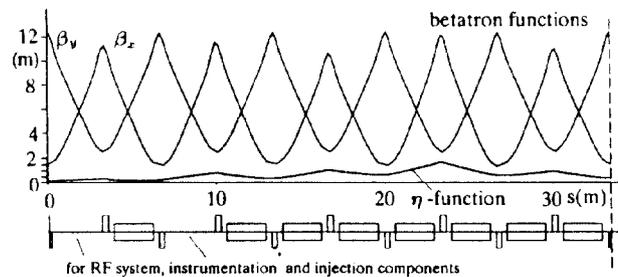

Figure 2
Magnet structure and lattice functions

quadrant of the ring and in Table 1 basic design parameters are compiled.

Table 1
Basic Design Parameters

Energy	E	3.0	GeV
Circumference	C	133.4	m
Cycling Rate	R	10	Hz
Intensity	N	$\geq 1.0 \, 10^{10}$	e^-/sec
Tunes:	ν_x/ν_y	6.25/4.18	
Linac Energy	E_{linac}	≥ 120	MeV
Linac Frequency	f_{linac}	2856	MHz
Linac Intensity	N_{linac}	$\geq 2.0 \, 10^{10}$	e^-/sec

III. COMPONENTS

A. Preinjector

To simplify the source components for the electron beam it was decided to use a thermionic rf gun [2],[3] being powered by 5 MW split off from the second linac klystron by a 7db coupler. The maximum pulse current from the rf gun has been measured at 1.5 ampere. Simulations of the gun design show that back bombardment is minimized to a level where the cathode temperature is determined by external heating as has been observed experimentally. After acceleration in the gun to 2.5 MeV the electrons pass through an alpha magnet for energy selection and bunch compression. The energy filter in the alpha magnet is set to about 15 to 20 % and from measurements at the end of the linac we conclude that the bunch becomes compressed to less than 1 psec. The energy spread of the beam at 120 MeV is reduced by adiabatic damping to abut 0.4%. A
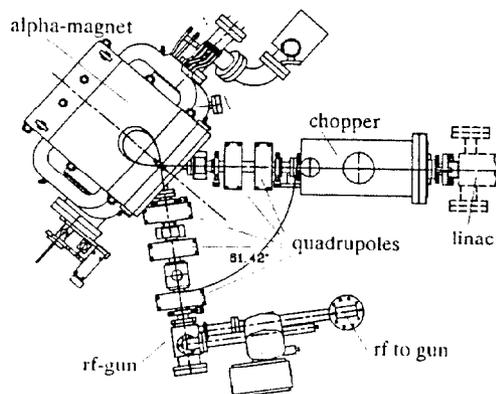

Figure 3
Rf gun, compressor and chopper unit

chopper unit [4] is installed between the alpha magnet and linac to facilitate the selection of only 3 S-band bunches. The beam is swept vertically across a small slit by a travelling wave allowing the passage of only 3 S-band bunches. Acceleration to 120 MeV occurs in three ten foot long linac sections. Each section is driven by a 35 MW modulator and klystron[5]. The rf power for the gun is split off the second klystron rather than from the first section to allow maximum acceleration to relativistic energies in the first section. This combination of an rf gun and a beam chopper eliminates the need for prebuncher, buncher sections and elaborate solenoid focusing along the linac sections. No such focusing is employed in this preinjector due to the significant energy of 2.5 MeV which greatly reduces the sensitivity of the beam to stray fields. The component arrangement of the electron source is shown in Fig.3.

B. Magnets

The booster magnets are designed for a cycling operation at 10 Hz and maximum field strength of 1.39 Tesla for future operation at 5 GeV [6]. The magnets must be constructed from laminated steel to avoid eddy current effects and heating. After R&D with different steel qualities,

US1005 steel was used because of it's excellent magnetic qualities. At 10 Hz measurements did not indicate significantly higher AC or eddy current losses compared to transformer steel. Each coil includes 19 turns for the main current and a pair of trim coils for orbit correction and compensation of induced voltages from the main coil. To simplify installation and alignment the bending magnet cores are constructed in five short pieces set directly on precision drilled pins on a single steel girder such as to form a "curved" magnet following the beam path (see Fig.4). The quadrupoles are constructed in four quadrants from US1005 steel and are powered in series with the bending magnets. Extra computer controlled trim coils are used to adjust the quadrupole strength.

C. Vacuum

The vacuum chambers in a synchrotron must be fabricated in such a way as to avoid eddy current losses and allow the magnetic field to penetrate the chamber wall to reach the beam orbit without distortion. Following the pioneering design for the DESY synchrotron [7], a stainless steel tube with a wall thickness of 0.3 mm was used for the booster vacuum chamber. Strengthening ribs surrounding the chamber every inch along the chamber prevent collapse of the chamber [8]. Pressure tests demonstrated stability of the chamber in excess of 10 atmospheres. The eddy current heating is negligible and the chamber temperature does not exceed measurably the ambient temperature within the magnets. No detrimental effect of eddy currents on beam dynamics has been observed. The vacuum chambers are constructed in 40 cm straight pieces and welded together at the correct angle to form a "curved" chamber, 2.5 m long and reaching through bending magnet, quadrupole and sextupole. Instrument modules are installed between individual chambers to accommodate pump port, beam position monitor, bellows and an isolating ceramic ring.

D. RF System [5]

Acceleration of the electrons is accomplished in a 5-cell rf cavity at 358.4 MHz. The cavity voltage must be controlled during acceleration to avoid too high synchrotron oscillation frequencies and amplitudes at low energy. The computer control allows to adjust the rf voltage at any point along the acceleration cycle for best beam stability.

E. Instrumentation and Control

Beam position monitors and orbit correction coils are installed [9] for beam control during ramping although orbit correction is done in DC mode and compensates for remnant field errors only. Diagnostic instrumentation [10] and timing systems[11] complement the electronic controls of the injector. The computer software [12] allows the control of all systems from a terminal. Specifically, magnet currents can be adjusted by pointing and moving the cursor to screen sliders. Time dependent adjustments necessary during energy ramping can be preprogrammed as well on
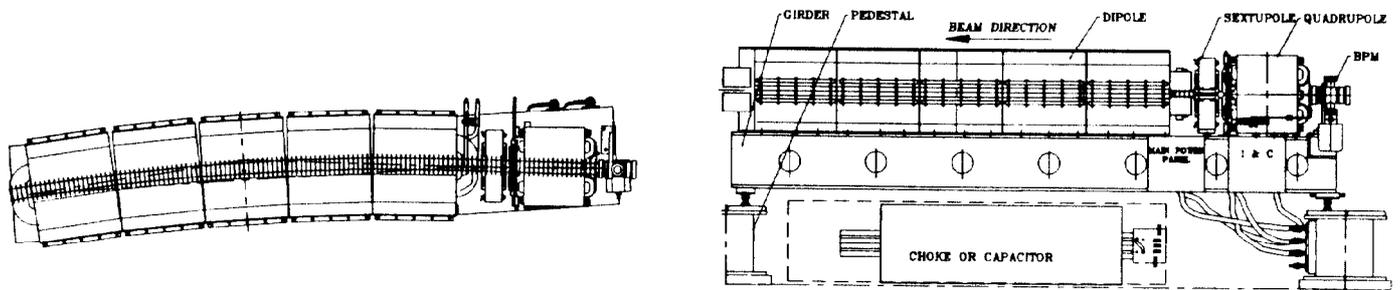
Figure 4
Top and side view of magnet girder

by adjusting function values on a diagram.

F. Power Supplies

The main magnets, bending magnet and quadrupoles, are powered from a single White circuit [13]. The specific field requirements of the focusing (QF) and defocusing quadrupoles (QD) are met by constructing both magnets in different length to produce the proper focusing to within 1 to 2 %. For fine adjustments all quadrupoles contain trim coils which are separately powered by computer controlled power supplies. This feature allows free adjustment of the quadrupole strengths and betatron tunes during the accelerating cycle for maximum beam stability. Horizontal and vertical beam steering is accomplished by trim coils in the bending magnets and in the quadrupoles. These corrections are static to correct mostly for remnant field errors. No orbit correction is provided for higher energies where orbit distortions are determined mostly by alignment errors. Due to the low sensitivity of the orbit to alignment errors in this lattice no such correction is necessary.

G. Injection/Ejection

A beam transport line from the linac to the booster ring includes energy analyzing equipment as well as capabilities to measure the beam emittance. Injection into the booster is performed on axis with a horizontal septum magnet and a pulsed kicker magnet[14]. A peaking strip signal from one of the bending magnets is used to trigger the kicker magnet at the correct field level. Ejection occurs at the end of the acceleration cycle by firing a kicker magnet guiding the beam into a Lambertson septum [15] and through vertical bending magnets into the beam transport line to SPEAR located in it's first section atop the booster ring.

IV. PERFORMANCE

The injector project has been completed by the end of November 1990 ahead of schedule and within budget. All design beam parameters have been achieved, specifically an intensity of more than 1.0^{10} electrons per second can be delivered to SPEAR[16]. This is sufficient to fill SPEAR to the nominal current of 100 mA in less than five minutes.

V. ACKNOWLEDGEMENTS

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