SABER OPTICAL DESIGN*

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Abstract

SABER, the South Arc Beam Experimental Region, is a proposed new beam line facility designed to replace the Final Focus Test Beam at SLAC. In this paper, we outline the optical design features and beam parameters now envisioned for SABER. A magnetic chicane to compress positron bunches for SABER and a bypass line that could transport electrons or positrons from the two-thirds point of the linac to SABER, bypassing the LCLS systems, are also discussed.

THE NEED FOR SABER

The high energy electron and positron beams from the SLAC linac have been in constant demand by researchers from many different scientific communities for many years. In the last decade, the SLAC Final Focus Test Beam (FFTB), combined with new bunch compression techniques, has opened up new areas of research in beam and plasma physics, ultra-short-pulse x-ray generation, laboratory astrophysics, and specialized accelerator diagnostic techniques. SLAC is the only place in the world that can provide the high peak current, high energy electron and positron beams that make this research possible.

The FFTB has recently been dismantled to make way for the construction of the Linac Coherent Light Source (LCLS). Several options for FFTB replacements were studied [1], and SABER was selected as the most cost-effective. If constructed as proposed, SABER will provide a means to continue delivering high energy, compressed electron or positron beams to experiments requiring these special beam qualities. When SABER is combined with a proposed new bypass line, it will operate independently of the LCLS facility.

PROJECT DESCRIPTION

SABER is designed to provide electron or positron bunches up to 30 GeV with at least $2 \cdot 10^{10}$ particles (3.2 nC charge) compressed to a spot size of $\sigma_{x,y} < 10\ \mu$m and a bunch length of <100 fsec (30 μm). Compression of positron bunches will be a new capability not currently available at SLAC or anywhere else. A beam of high-energy compressed positron bunches is essential for continuing the investigations of plasma wakefield acceleration effects, which are of particular interest for their application to future linear colliders. The demand for low-intensity test beams is also expected to continue because of the ongoing development of detector systems and beam instrumentation for use both at SLAC and elsewhere.

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SABER will use the first 200 m of the South Arc of the currently unused SLAC Linear Collider (SLC). This transport system has not been operated since 1998, but the components have been preserved in their original locations, and can be restored to operation with modest effort. The experimental region will be set up in the existing arc tunnel approximately 10 m below ground, where it is well shielded by the earth above it, and where the full beam power can be absorbed safely. This is a significant advantage over the existing FFTB facility, in which radiation safety considerations have imposed limitations on beam power for several important research programs. A new controlled entry point in the existing Southwest Adit spur tunnel will provide users with convenient access to this experimental region, enabling them to work on experimental apparatus without interfering with other beam programs at SLAC.

General Layout

The SABER project consists of modifications to three areas of the SLAC linac and beam delivery systems. The overall site layout is shown in Fig. 1. The bunch compressor in Sector 10 of the linac will be upgraded to compress positron bunches as well as electron bunches. A new bypass line will be installed to extract the accelerated beam from the linac at Sector 20 and transport it to the Beam Switch Yard (BSY). The bypass line will then be coupled to the South Arc where the bunch will be further compressed and focused as it is delivered to an experimental region near the Main Control Center.

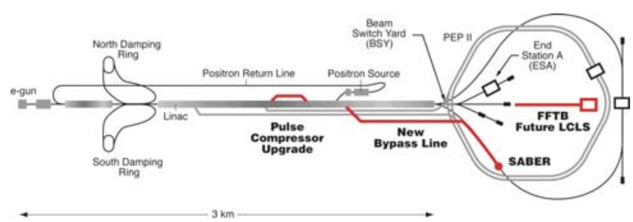

Figure 1: SABER at the SLAC accelerator facility.

South Arc

During SLC operation, the accelerated positron beam was separated from the electron beam and deflected into the South Arc by a dipole magnet at the end of the linear accelerator. From this point, the beam was further bent and focused as it passed through the Beam Switch Yard to the first of 460 combined-function alternating-gradient magnets which guided the beam to the final focus. These magnets formed 23 achromatic groupings of 20 magnets each. Each achromatic group was designed to deflect the beam through a total angle of approximately 10.3° without changing its size, shape, or angular divergence.

Following the second achromatic group is a 60 m long straight section designated the Instrument Section, which consists of a sequence of quadrupoles, dipoles, and various diagnostic instruments. This straight section will be modified with a beam dump and a dispersion-free drift section to accommodate experimental apparatus. Additional quadrupoles will be added to focus the beam to a small spot. If needed, a portion of the arc downstream of the Instrument Section could be removed to create more space for experimental apparatus.

Positron Compressor

A bunch compressor system was installed in Sector 10 of the linac in 2002 and was used in conjunction with previously existing accelerator systems to compress electron bunches to less than 100 fsec as they were delivered to experimenters in the FFTB tunnel. The key components of the electron compressor system are four identical dipole magnets which form a magnetic chicane. Upstream of this chicane, the linac RF system is tuned to introduce a correlation between the energy of the electrons and their longitudinal position within the bunch, such that the higher energy electrons are shifted toward the trailing end of the bunch. As the bunch passes through the chicane, electrons with lower energy follow a longer path, allowing higher energy electrons to catch up, resulting in a shorter bunch.

This system works well for electron bunches, but cannot be used for positrons. This lack of symmetry comes about because positrons are produced by first accelerating electrons, which must pass through the same section of the linac. The compressor system as it currently exists allows only negatively charged particles to pass. This limitation can be overcome by installing two more dipole magnets identical to the others, but on the opposite side of the linac. The existing support structures will need only minor modifications. New vacuum chambers will be needed to pass the diverging and recombining beam paths of the electrons and positrons, and additional instrumentation will be required to facilitate steering and focusing the two beams simultaneously.

Bypass Line

The layout of SABER magnets in the bypass line and the beginning of the South Arc is shown in Fig. 2. The bypass line will start with a new bending magnet installed along the linac in Sector 20 downstream of the existing positron production system and upstream of the new LCLS injection system. From this point, an accelerated beam can be deflected from the linac and transported gradually upwards and outwards to a new trajectory parallel to the linac above the walkway in the existing tunnel. The beam will be transported nearly 1000 m through a beam pipe suspended from the tunnel ceiling to the BSY, where it will be deflected through a series of bend magnets to match the original South Arc beam trajectory and beam parameters at the existing 51B2 bend magnet. At this point, the beam is offset from the linac about 30 cm. The bypass line will

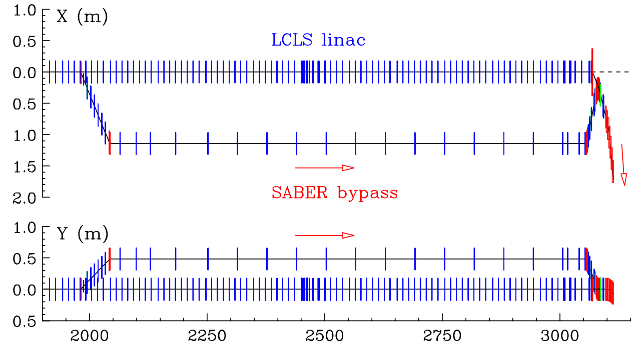

Figure 2: Geometrical layout of bypass magnets.

also require a sequence of quadrupole and steering corrector magnets to focus and steer the beam. In addition, sextupole magnets will be needed in the dog-leg bending sections near the beginning and end of the bypass line to compensate the second-order chromatic effects. The vacuum system, mechanical supports, diagnostic instruments, and many of the magnets are identical or very similar to the corresponding devices in the two existing transport lines used to deliver electrons and positrons to fill PEP-II.

BEAM OPTICS

The SABER optics functions are shown in Fig. 3. The bypass line consists of the initial achromatic dog-leg section, a long straight section with six $45°$ FODO cells suitable for emittance diagnostic devices, and a second dog-leg for optical and geometrical matching into the South Arc. Due to space restrictions in the BSY, the second dog-leg section is very short, which requires strong focusing and a high β peak. The dog-leg bends are rolled to provide both horizontal and vertical bending. This section is then matched to the small β functions of the original South Arc. Finally, a new low-β optical configuration is added in the South Arc Instrument Section, consisting of four matching quadrupoles and a final doublet 2 m before the Interaction Point (IP). Eight sextupoles are also included in the bypass dog-legs to compensate chromatic beam growth. This optical configuration results in a round beam spot with $\beta_x = 1$ cm and $\beta_y = 10$ cm and zero dispersion, assuming a normalized emittance of $\gamma\epsilon_x = 50$ μm and $\gamma\epsilon_y = 5$ μm.

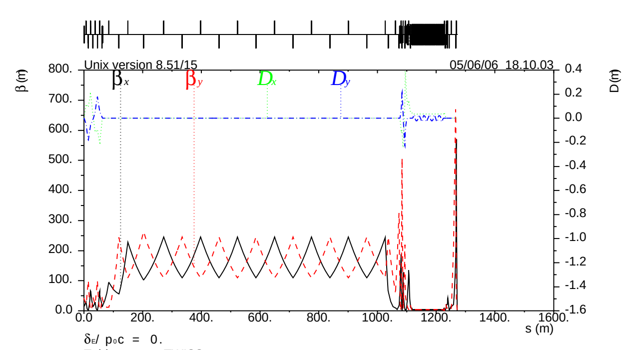

Figure 3: β functions and dispersion in SABER from the linac Sector-20 extraction point to the final focus IP.

Beam Tracking

Tracking programs that include 2nd order effects have been used to compute the beam properties that can be expected with SABER: LiTrack [2] for longitudinal phase space optimization, Elegant [3] for 6D tracking with coherent synchrotron radiation (CSR), and Dimad [4] for 6D tracking with synchrotron radiation (SR).

The longitudinal bunch distribution is compressed sequentially in the RTL compressor, the Sector 10 chicane, the bypass line, and the South Arc, and can be optimized by varying the damping ring (DR) extraction phase and the Sector 2–6 RF phase. Four configurations have been studied: "Nominal", which produces a highly compressed bunch, but with a large energy spread, "Low ΔE" which maintains a much smaller energy spread, but delivers a longer bunch, "Low E" which provides a shorter bunch by reducing the DR energy (from 1.19 to 0.9 GeV), and the "No bypass" option for the first phase of the project before the bypass line is ready. The longitudinal distribution at the IP for the nominal case is shown in Fig. 4. The rms of the Gaussian fit obtained with LiTrack is $\sigma_z = 18.5\ \mu$m.

The effect of energy spread on beam size growth at the IP was investigated in Dimad for a flat $\Delta E/E$ spread as shown in Fig. 5. With sextupole corrections and SR effects included, the IP beam size is constant up to an energy spread of about 3% full width and increases to about 10 μm at 4%. Without sextupoles, the beam size grows rapidly with energy spread (except in the "No bypass" case, where sextupoles are not needed). The effect of SR is a 0.1% energy loss at 30 GeV, but this is unimportant when the energy spread is large. The IP beam parameters for the four configurations are summarized in Table 1.

The strong bunch compression imposes tight pulse-to-pulse stability tolerances on RF phase, voltage, and charge. The longitudinal jitter budget listed in Table 2 results in an rms variation in peak current (column-2) of 20% or an rms variation in relative energy (column-3) of 0.1%. Each entry is the rms of a statistically independent source of random variation, such as bunch charge or RF phase and voltage in a portion of the machine. These tolerances are consistent with observed performance for time scales up to about 10 seconds. An active feedback system will be needed to control large slower variations.

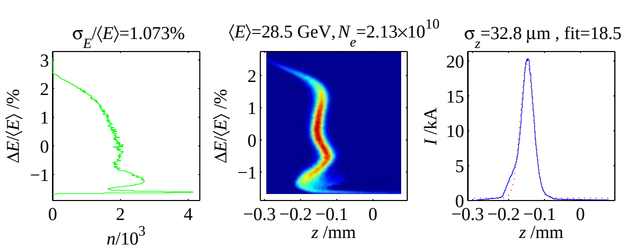

Figure 4: LiTrack longitudinal beam distribution at IP for the nominal case: $\Delta E/E$, phase space, bunch length.

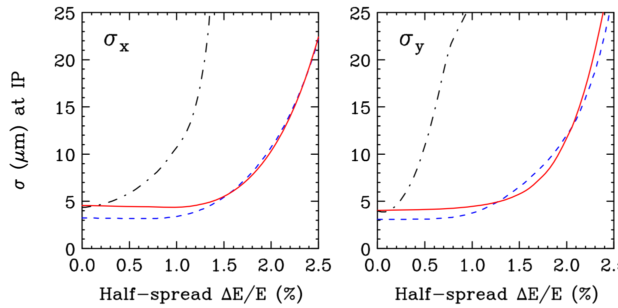

Figure 5: $\sigma_{x,y}$ at IP versus half-width of a flat energy spread: a) with sextupoles and SR (solid line), b) with sextupoles and without SR (dashed line), and c) without sextupoles and with SR (dash-dot line).

Table 1: IP beam parameters obtained by Dimad simulation. I_{pk} is peak current and $(\frac{\Delta E}{E})_{tot}$ gives limits of the bunch spectrum; σ_z, σ_x, σ_y, are the rms of Gaussian fits.

Option	$\boldsymbol{\sigma_z}$ **[μm]**	$\boldsymbol{I_{pk}}$ **[kA]**	$\boldsymbol{\sigma_x}$ **[μm]**	$\boldsymbol{\sigma_y}$ **[μm]**	$\boldsymbol{(\frac{\Delta E}{E})_{tot}}$ **[%]**
Nominal	19.4	20.4	4.87	5.43	−1.8, +2.5
Low ΔE	44.7	9.2	4.35	4.11	−2.1, +1.2
Low E	12.7	29.6	4.94	5.43	−1.9, +2.5
No bypass	18.8	21.3	6.56	5.43	−3.0, +1.8

Table 2: Longitudinal jitter tolerances for the nominal configuration.

Parameter	$\boldsymbol{\frac{\Delta I_{pk}}{I_{pk}} = 0.2}$	$\boldsymbol{\frac{\Delta E}{E} = 10^{-3}}$
RTL RF phase (°)	0.1	0.1
Sect. 2-6 RF phase (°)	0.1	0.1
Sect. 10-20 RF phase (°)	0.3	0.6
RTL RF voltage (%)	0.1	0.6
Sect. 2-6 RF voltage (%)	0.3	0.1
Sect. 10-20 voltage (%)	0.6	0.08
DR extract phase (°)	0.3	0.6
Relat. bunch charge (%)	2.5	3.0

CONCLUSION

The SABER facility is being proposed as a replacement for the FFTB, which has recently been dismantled to make way for the LCLS at SLAC. SABER will provide a means for compressing and focusing bunches of high energy electrons or positrons and delivering them to an experimental area in the tunnel originally built for the SLC South Arc.

REFERENCES

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