SLAC STORAGE RING BEAM TRANSPORT INSTRUMENTATION AND OPERATION*

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Abstract

Accelerator beam transport system instrumentation, and operation in general, is a matter of routine engineering. Given sufficient funds and space, an optimum design with maximum effective human interface usually prevails. However, given a very low budget and the criteria that the alternately injected e^-, e^+ beam be run simultaneously with a minimum of six other primary beams, a deviation from standard design practice and operation philosophy was required. This paper will describe the requirements necessary to bring the alternate e^- or e^+ beam through the 400 meter long beam transport system with an initial common bend of 48° then a separate bend of 12° each for each of the electron and positron beam paths. The approach to effectively fulfill the operation requirements was a coherent mixture of adding controls to existing similar function panels and a multitask operation chassis. This multitask chassis contains different but interrelated functions in a single panel. The operation of this multitask panel is also operable from the distant and separate SPEAR control room. The deviation of general engineering practices resulted in an optimum performance per cost balance.

Introduction

The beam transport system for the SLAC storage ring (SPEAR) is comprised of the usual complement of magnets for focusing, steering, and energy defining. The transport is a "Y" configuration with each branch of the fork designed to provide an achromatic beam alternately to each of the two injection points in the ring. The transport beam monitoring devices are similar to that of the existing beam transport systems for beam intensity, position, profile, and spectrum display. Here, however, is where all similarities with other SLAC transport components end, and a challenging dissimilarity of operational requirements begins. The usual one beam setup per experiment with infrequent major parameter changes no longer applies to the SPEAR operation. The SPEAR beam parameters are drastically different than the normal beams.

The problems involved in adding a complex and operationally different beam to an established routine of six other beams and the chosen solutions to these problems are the themes of this paper. We will compare the detailed differences between SPEAR and existing beam requirements; discuss the implications of the SPEAR operation integrated with six other primary beam operations; and evaluate the final choice of a task-oriented SPEAR control unit designed to meet the operation criteria.

Major contributors to the works involved in the design and construction of the SPEAR transport and instrumentation reported here have been M. Baldwin, J. Berk, T. Constant, K. Crook, J. Harris, L. Horton, A. Sabersky, and D. Walz.

Description of SPEAR Transport System

The physical configuration and the beam optics of the transport system greatly influence the operational criteria and instrumentation requirements. The number of beam profile monitors and their location is an obvious example of the instrumentational dependence of the beam transport optic design. The beam spot or profile viewing device must be located at or near the beam waist or minimum for effective viewing. The choice of the beam waist location is more than just practicality, i.e., the profile monitor must be significantly larger than the beam spot, but it also must be properly coupled with steering dipoles so that the beam spot may be easily maneuvered. If the monitor is properly located, it can also be used for position indication, and the study of possible beam interception or aberration. The number and location of the beam intensity and position monitors is another example of dependency upon the transport configuration. The intensity and position monitors are generally located at the beginning and end of the transport, and before and after beam limiting devices; i.e., collimators and slits, long drift sections and large angle bends. The optimum number of various types of monitors for effective operation is the least number which will still provide sufficient diagnostic information. Excessive monitors may adversely affect operation efficiency by burdening the operators' decision in the selection of the monitors and creating the difficulty of multisignal interpretation.

But first we should present a brief picture of the total storage ring operation (Fig. 1). Beginning at the injector in the accelerator, a 10-sector beam (nominally 7 GeV) is used to bombard a thick tungsten or copper target in sector 11. The pair production of e^- and e^+ is then captured by the specially designed sector 11 positron source facility and accelerated to the required 1.5 GeV primary energy. The e^- beam may also be produced by the injector electron gun and accelerated to 1.5 GeV. The beam enters the beam switchyard and is pulsed .136° to the north into the SPEAR transport. The beam is then run through beam line 15. Depending on the particle's polarity, it will either bend northeast via beam line 17 for e^- or southeast via beam line 16 for e^+ and injected into the ring at the end of those two lines.

The SPEAR beam transport is 400 meters long (see Fig. 2). The basic beam optic design is to provide a well-focused, approximately 2 mm diameter, achromatic beam into each of the storage ring septums. The optics start with a point-to-point focus from the first collimator in the beam switchyard to the splitter magnet 15D9, and a point-to-parallel beam through a 65-meter-drift section then refocused to a point by the last set of quadrupoles before injection into the ring. The focusing elements in beam line 15 consist of five quadrupoles. They are 15Q1, 2, with 15Q3 as a symmetry quadrupole and 15Q4, 5. Beam lines 16 and 17 each have four more quadrupoles, i.e., 16/17Q1, 2, 3, 4. The primary beam has a total bend of 72° after the initial .136° bend. There are nine bending magnets (15D1-9) in beam line 15 totaling 60°, and an additional 12° bend by each of the branched beam lines (16/17D1). In addition to the eleven bending magnets and thirteen quadrupoles, there are twelve dc steering magnets, one safety pulse magnet (to limit pulses to 20 pps), and one .136° pulse bending magnet. Other beam line devices include eight profile monitors made of cesium iodide crystals, except one which is coated with ZnS, seven intensity monitors, five position monitors, two beam stoppers, five isolation valves, two radiation safety collimators, one slit, two sets of energy spectrum foils, one safety permanent magnet, four protection ionization chambers, one long ionization chamber and two temperature detectors. For economic reasons, the eleven dc bending magnets are connected in series and are powered by one power supply. Polarity switching to accommodate e^- and e^+ is done in the power supplies and is required for all 15 line common magnets except 15AP1 and 15D9. All magnet power supply status is summarized at the power supply located away from the control room. The summary is then sent to the SPEAR control chassis in order to minimize wiring and reduce cost. This economic constraint at times hinders

*Work supported by the U. S. Atomic Energy Commission.

rapid fault diagnosis. Although the SPEAR transport complexity is not significantly greater than the other existing beam transports, it has added a considerable operator work load. This added work load, under present operating conditions, is essentially borne by one of the two operators who is already responsible for at least two other beams. The implications of this extra operation activity depends largely on the logic and sophistication of the instrumentation and control. Minimizing the operation steps, and still meeting the SPEAR beam specifications, will reduce the work load.

SPEAR Primary Beam Specifications

One major factor which affects beam operation requirements is the primary beam specifications of the user. These beam specifications basically dictate the rudimentary design of the instrumentation and controls, and the work load factor. There are many differences in beam specifications compared to the existing six beams. These differences and problems are detailed in the operation criteria for SPEAR section. We will first discuss the users' primary beam specifications, then the operational tasks, and finally the instrumentation and controls.

The primary beam specifications are as follows:

(a) Primary Energy: 1.5 GeV.
(b) Beam Intensity: Maximum possible ($e^+ \approx 3$ mA peak, $e^- \approx 7$ mA peak from the positron source, or 15 mA peak e^- from the gun directly).
(c) Pulse Width: Each pulse consists of two bursts of 7 ns width spaced 780 ns apart. (The two bursts are within a 1.6 μs window which is the typical pulse width for other beams.)
(d) Particle: Alternate e^- and e^+ particles. Storage ring is to be injected first with e^+ particles. When an appropriate intensity is reached (at present operation the fill time is about 10 minutes), the polarity of particles will be switched to e^-. The filling time of e^- is approximately 5 minutes. After both e^- and e^+ beams are stored, the colliding beam experiment may then begin. The expected ring beam life is approximately two hours.
(e) Repetition Rate: 20 pps (primary beam).

Operation Criteria for SPEAR

The operation criteria, in this case, are defined as the procedures of an optimum operation method or the minimum number of steps which the operators need to perform in order to achieve the most efficient operation. Once this criteria is defined, it is used as the guidelines for the design of the instrumentation and controls. In order to establish the operation criteria, careful review of existing operation experience is needed. The differences in beam requirements and the implication must also be evaluated. A workable solution may emerge to satisfy all of the detailed requirements.

There are two significant differences between the SPEAR primary beam specifications and the other six existing beams. (1) The short term alternate mode of e^- and e^+ rather than the long term single polarity particle; (2) The two 7 ns bursts per pulse rather than the usual 1.6 μs with all bunches or knockout bunch structured pulse. Although the variations are seemingly slight, they do create ill-proportioned implications. It is assumed that the usual beam operation is well-published and will not be emphasized except the differences will be stressed.

The requirement of the alternate e^+ and e^- injection, and then the no beam requirement once the storage ring is filled (the circulating storage ring beams are now independent of the primary beam) create at least two new operational tasks: (1) To monitor and maintain one of the unused particles while the other particle is being injected; (2) To monitor and maintain both unused e^- and e^+ particles when the storage ring is filled and colliding beam experiment commences.

The first operational task is not being done due to equipment and transport limitations. Presently, we can only maintain or monitor one particle at a time. The reason for monitoring the unused particle is because the crucial beam parameters, like energy and steering, do change and remain undetected, if the beam if off, although the accelerator and transport magnet values are preset and remain unchanged. For the second operational task, both e^- and e^+ beams are maintained by alternately cycling into beam line 15. This cycling is done automatically. Operator effort is only needed for diagnostics and rectification of steering and energy variation. The purpose for this intense beam-keep-alive effort is to enable beam injection on demand. Since the fill cycle, beam tuning, and other downtimes are interruptions to actual experimental beam time, these interruptions must be minimized to increase efficiency. With an average of 15 minutes of fill time for both particles for each two hour cycle, a mandatory 12.5% unproductive physics time is accrued even though the accelerator beam is 100% available. Any additional time loss due to beam tuning and equipment failures will substantially further reduce the efficiency.

Another operational problem is the unusual two bursts (7 ns per burst) per pulse where the low beam intensity is barely detectable by the existing accelerator beam guidance monitors which were designed for high intensity beam application. This problem is particularly acute in the e^+ mode where the intensity is at noise level compared to the other six beams being run simultaneously. To enhance the signal to noise ratio needed for beam tuning, the beam structure is changed from 780 ns burst spacing to 100 ns burst spacing, while increasing the number of bursts from two to about sixteen.

Another minor demand on the instrumentation and control is the provision for using only 5 pps for monitoring and giving away the other 15 beam pulses per second to other experiments when the ring is full. This type of pulse rate give-away when the beam is not used is a common practice at SLAC to insure maximum usage of pulse rate.

To summarize and re-examine the operational tasks, we need to "tune" the beam which requires a different beam structure, "fill" the ring which requires both e^- and e^+ particles available on demand. The instantaneous availability demand creates the necessity of "monitoring" and maintaining the beams when not in use.

The major operational tasks now take the form of three modes: "TUNE", "FILL", and "MONITOR". Each of the operational tasks is composed of several functions. The three modes of operation are pre-conditions or preludes to actual beam manipulation. They set up the proper conditions for the beam but do not tune the beam. These three mode selects are exclusively in the SPEAR control unit. Since the actual beam tuning is the same as other beams, the actual beam tuning controls for SPEAR are appropriately integrated with the other beam tuning controls.

The detailed functions required by each mode are delineated in the following functional block diagrams.

TUNE Mode

In this mode of operation, the operator needs only to actuate one control and the five steps for the preparation of TUNE task are completed. Although the actual beam tuning is still required manually, the various transport system pre-requisites are automatically performed but not totally computerized.

The reasons for the various steps prior to tuning are:

(a) The slit is closed in order to insert the spectrum monitor foils in the beam line so energy spectrum may be viewed for tuning (the foils are mounted on the slit). Closing the slit also reduces unnecessary radiation downstream.

(b) 100 ns burst spacing is selected to increase available signal for accelerator monitoring for a better signal to noise ratio.

(c) The selection of 20 pps is to improve accelerator and beam transport monitor signal presentation.

(d) The computer magnet tolerance scan is turned off so that magnet values may be changed during the tuning without actuating the alarm. After the magnets are set, the tolerance scan may be reactivated.

(e) The computer assisted energy spectrum scan is turned off in order to disable the alarm while energy is being tuned.

FILL Mode

In this mode of operation we assume that the beam has been properly tuned and only minor corrections for steering or energy are needed. When the "fill" control is actuated, all required conditions will be ready for the performance of this task. If magnet values are changed, a new tolerance scan strobe input is needed. The various steps are self-explanatory.

MONITOR Mode

The monitor mode is a combination of Tune and Fill operations. The major addition is the automatic switching of e^- and e^+ beams. Since the equipment cannot monitor both e^- and e^+ beam simultaneously, the e^- and e^+ are alternately switched and monitored at five minute intervals. This added switching function automatically suppresses the beam, switches all magnet polarities, except beam line 16 and 17 magnets, changes beam line pattern and trigger assignment, and turns the beam back on when all conditions are "go". One other difference is the reduction of 20 pps to 5 pps where the remaining 15 beam pulses are given away to other users. Otherwise all functions are the same as above.

Task Oriented, Multitask SPEAR Control Unit

The final hardware decision was to separate the unique SPEAR controls and the usual beam controls. A special multitask control panel was designed and is installed in each of the two console positions. The similar beam controls, which are common to other beams, are integrated or added on to existing beam control panels. These include: accelerator controls, focusing, dc or pulse steering, profile monitor selector, trigger assignment, vacuum controls, and personnel protection controls. (See Fig. 6.)

The SPEAR control unit is designed to implement the three modes of operation with individual mode select and controls for the various related functions. This individual control may be used as manual bypass if a subroutine change in a given mode is desired.

This control unit is divided into two hardware parts, a control and status panel, which is used by the operator, and a logic package which is located in the backup racks. The logic package is the central processor which implements the various requests only when all conditions or interlocks are satisfied. Various controls are interlocked to minimize human error. A remote controlled panel is provided in the SPEAR storage ring control room. It is used whenever possible to lighten the operator work load in the Main Control Center, where all the beams are being run.

The various functions on the SPEAR control unit may be divided into two main categories, namely control and status. Aside from the three major mode selections, the control subroutines are defined as follows: (1) Beam suppress/enable; (2) automatic suppress bypass; (3) e^+/e^- beam command — automatically selected accelerator beam line for e^- or e^+/change related triggers for pulse magnets, switch polarity on appropriate magnets and set values to preset levels; (4) slit control — this control is also interlocked with the personnel protection logic; (5) beam rate select — 20 pps or 5 pps with automatic give away of the pre-assigned 15 pps; (6) MCC/SPEAR control select — this is a dual control select where this panel may be controlled by SPEAR, storage ring control room, or the Main Control Center.

The SPEAR control room panel has less control functions than the one in Main Control Center, however, it is possible for the SPEAR control room to select "FILL" or "TUNE" mode and the desired particle polarity either e^- or e^+ when the MCC control panel is set to SPEAR control mode.

The status information provided in MCC is as follows:

(1) Magnet and power supply on/fault — a summary of the twenty magnet power supply interlocks both internal and external.

(2) Tolerance scan magnet value OK/error — an in or out of tolerance information from the computer.

(3) Tolerance spectrum OK/error — an in or out of tolerance information from the computer.

(4) Storage ring interlock complete/incomplete — interlocked to prevent the opening of 15SL1 slit when the storage ring interlock is incomplete.

Computer Assisted Operation

The many repetitive and monitoring functions required by the SPEAR operation are ideally suited for computer assistance. Although closed-loop controls are not yet a reality, many monitoring functions are done by the computer. A "touch panel", computer generated video display with cross wire contacts on the display surface, is used to display magnet power supply values and tolerance information. Enabling of the magnet power supply tolerance scan can also be done via the "touch panel". The energy tolerance scan is also done in the same manner. General messages and status are presented in the video display unit.

Closed-loop controls for beam operation in terms of steering and energy correction are being studied as a general program for all beams.

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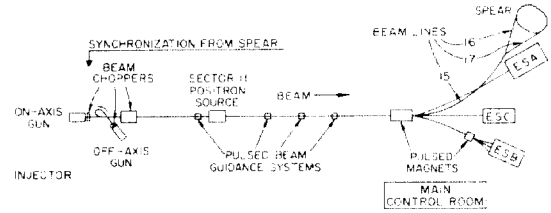

Figure 1.

LEGEND					
SYM	LTR	DESCRIPTION	SYM	LTR	DESCRIPTION
	A	MAGNET, D.C. STEERING		PR	BEAM PROFILE MONITOR
	AP	MAGNET, PULSE STEERING		PS	VACUUM PUMP STATION
	B	MAGNET, D.C. BENDING		Q	MAGNET, QUADRUPOLE
	C	COLLIMATOR		S	BEAM ENERGY SPECTRUM INDICATOR
	D	DUMP		SL	ENERGY DEFINING SLIT
	I	CURRENT INTENSITY MONITOR		SM	MAGNET, SAFETY (PERMANENT)
	TD	TEMPERATURE DETECTOR		ST	BEAM STOPPER
	IV	ISOLATION VACUUM VALVE		—	WINDOW, VACUUM
	P	BEAM POSITION MONITOR		PM	MAGNET, PULSE BENDING
	IC	IONIZATION CHAMBER			

NOTES.
1 FAST PICK-UPS ARE INSTALLED ON INSULATED GAPS.
2 INTENSITY MONITOR SENSITIVITY
a 15I1 100 mV/ma (PROCESSED SIGNAL) STRIP LINE PICK UP
b 15I2 3.5 mV/ma TOROID
c 15I2A
d 15I3 100 mV/ma (PROCESSED SIGNAL) STRIP LINE PICK UP
e 16I1,2 100 mV/ma (UNPROCESSED SIGNAL)
f 17I1,2 100 mV/ma

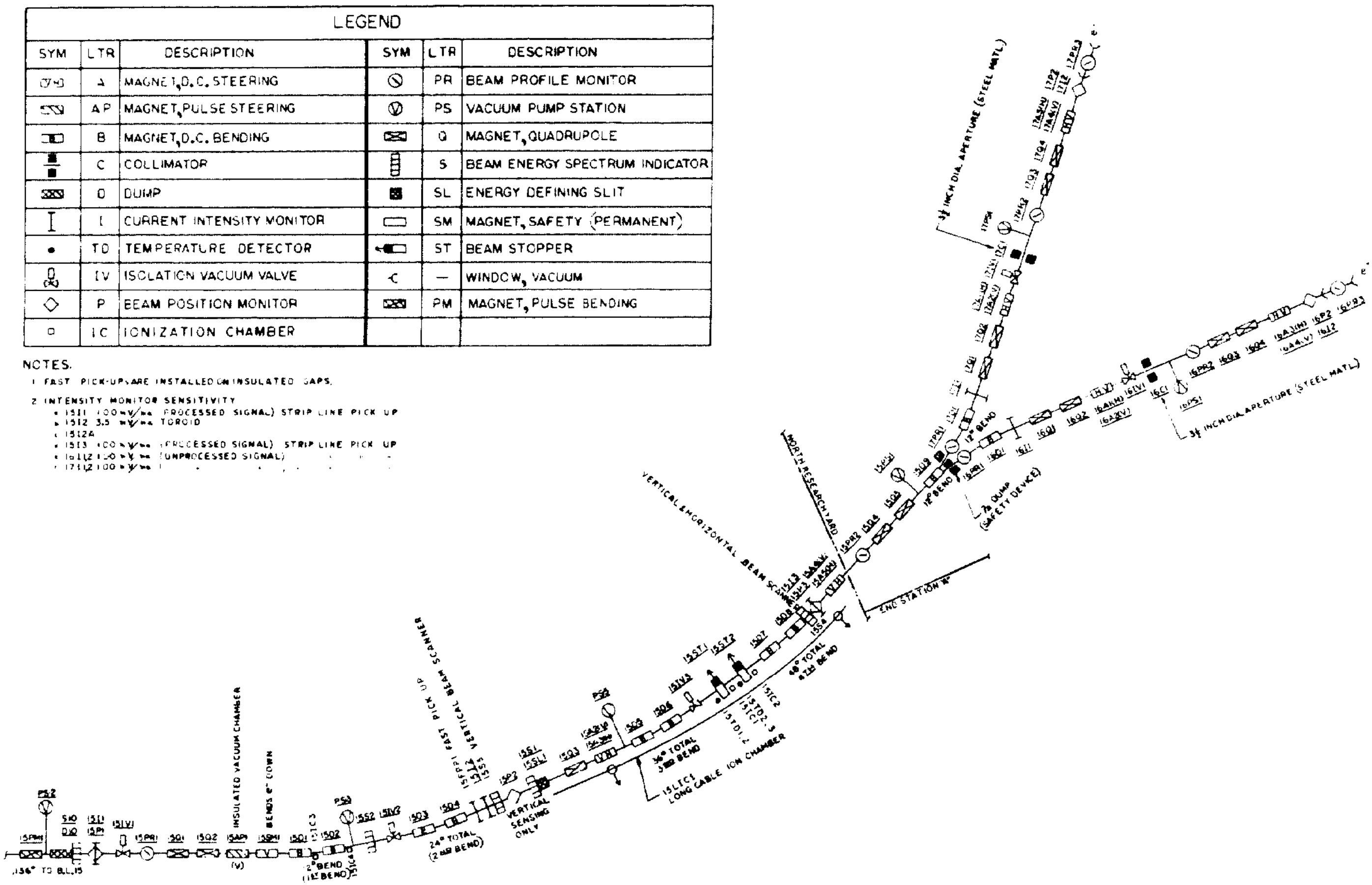

Figure 2.

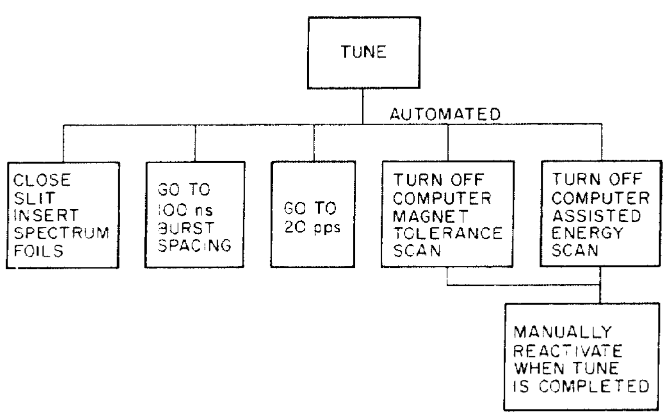

Figure 3.

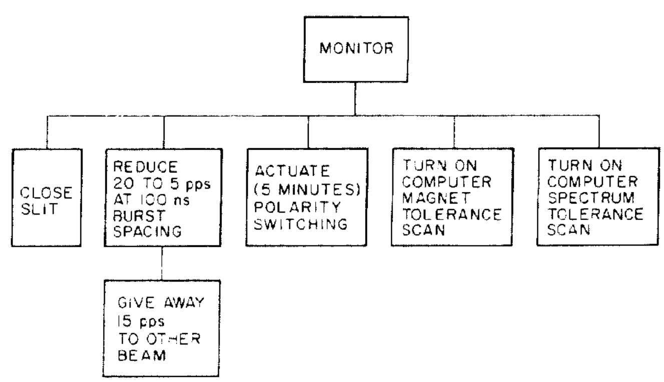

Figure 5.

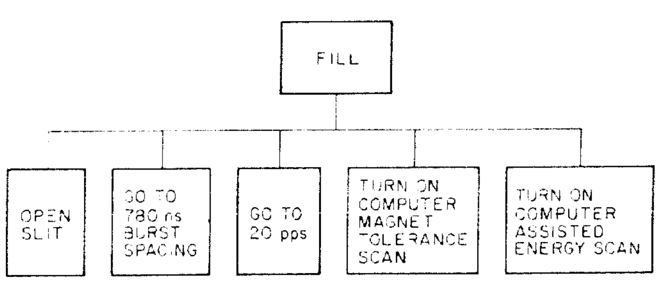

Figure 4.

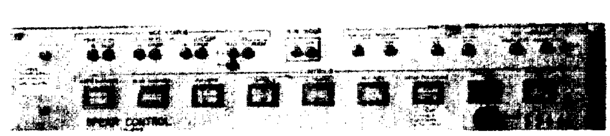

Figure 6.