

## SUPERCONDUCTING FINAL FOCUS FOR THE SLAC LINEAR COLLIDER\*

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Triplets composed of superconducting quadrupoles have been built and installed as the final focusing element for the high-energy positron and electron beams of the SLAC Linear Collider. Special features include independent alignment to 100-micron tolerance inside a common cryostat; non-magnetic materials to allow operation inside the detector's solenoid field; a continuous-flow helium-only system using 50-meter-long flexible transfer lines; and complete operation of the system before installation. The mechanical design and cryogenic operation experience are presented.

### INTRODUCTION

The Superconducting Final Focus was designed to solve several novel and difficult requirements posed by the experimental program at the SLAC Linear Collider. Machine optics require high-gradient (120 T/m) precisely aligned magnetic quadrupoles to focus the 50 GeV/c electron and positron beams to few-micron-diameter spots[1]. The new physics experiment for this facility, the SLC Large Detector (SLD), requires focusing elements that can work in the presence of its 6-Tesla solenoidal field and with as small an encumbrance of the detector area as possible. Finally, this new focusing system had to be made ultra reliable with all controls remotod, be completely tested and aligned in final form offline, and then installed with as few changes as possible.

These criteria guided the design of the focusing system as follows:

The high-gradient and external-field conditions were met by using superconducting quadrupoles with non-magnetic materials. Precision alignment was achieved by pinning the magnet coils and laminations into stiff cylinders which formed part of the cryostat. These cylinders were adjusted from the outside through low-loss gimbals and supports while monitoring the field position through a probe in a warm bore on the magnet axis.

The reliability, testing, and installation issues were solved by using simple pool-boiling helium-only cryostats continuously fed by flexible, low-loss transfer lines.

A schematic overview of the system is shown in Figure 1. It has been successfully operating at the SLC since early 1991.

### MAGNETS/CRYOSTATS

Each of the three quadrupole magnets, which were designed and fabricated at Fermi National Laboratory [2], is precisely located, pinned and welded inside, close-toleranced, mechanically stiff, machined 304L stainless steel tubes (600/1200-mm long, 170-mm OD  $\times$  7.6-mm wall), which also form part of the helium vessel. The three vessels/magnets are interconnected by 180-mm OD stainless steel bellows which allow independent movement. The 44-mm OD  $\times$  1.5-mm cold bore is constructed similarly.

Each helium vessel is fixed at its center by an epoxy composite gimbals, which locates and retains each vessel/magnet along the magnetic axis while allowing sufficient transverse freedom, (Fig. 2a).

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Precision transverse alignment of each individual magnet inside the 3800-mm long, 330-mm OD  $\times$  25.4-mm wall, stainless steel vacuum vessel is made by four (2 horizontal, 2 vertical), low heat load, positive displacement, screw action adjusters, each acting against an opposing return spring, (Fig. 2b,c). These pusher/adjusters accommodate all axial and transverse thermal contractions and a vertical sag of 6-mm from the cantilevered cryostat each time the detector end cap door, which forms part of the front external support, is opened. A schematic of the positional tolerances for the triplet magnets is shown in Fig. 3. The three magnets were aligned to within  $>50 \mu\text{m}$  with the system cold and powered, with little or no displacement following thermal cycles or mechanical movement.

## CRYOGENICS

Due to space restrictions in the experimental hall pit, the CTI-4000 liquefier, supply dewar and distribution valve box are located external to these areas at ground level. A gas/liquid phase separator is incorporated in the valve box to minimize the helium vapor fraction introduced by the dewar supply line, valves and valve box. This vapor is used to cool the valve box screen.

Liquid helium is supplied via low loss, flexible, coaxial transfer lines, of the type developed by CERN/Kabelmetal[3,4]. These lines are 58 and 76-m long, each having a vertical drop of 18-m. The quality of the liquid helium delivered to the cryostat disconnect box is such that no further phase separation is required. The helium vessel and disconnect box are thermally shielded by vapor cooled, copper radiation screens. A schematic of the system is shown in Fig 4.

Condensation on the 5000A vapor cooled current leads is eliminated by mounting 2 temperature controlled, 200W, cartridge heaters inside each lead connector block, an important consideration since access for ice/water removal or maintenance would be highly disruptive.

Cooldown of the triplets to 100K is carried out by passing liquefier supply gas, at a pressure of 2 bar, via a heat exchanger located in the liquefier LN<sub>2</sub> supply dewar through the valve box and flexible lines to the triplet disconnect box/liquid reservoir. The gas passes from the disconnect box, through the cryostat helium vessel and magnets to exit at the vessel end, returning via the cryostat heat shields and external heat exchangers to compressor suction. During cooldown only a small fraction of gas (50 l min<sup>-1</sup>) is returned via the transfer line shield. Progressively closing a manually operated bypass valve across the LN<sub>2</sub>/He heat exchanger permits uncomplicated and effective control of cooldown temperature and rate. Warm up is the reverse of the above procedure. The process takes  $< 36$  hours.

Final cooldown and liquid helium fill from 100K, takes  $< 6$  hours. The disconnect box/reservoir levels are held at  $\pm 1.5$ -mm via proportional control valves, located in the valve box, which maintain quasi constant helium flow to each triplet. Cryogenic performance and operating parameters for all three triplets were practically identical and are summarized in Table 1.

The extraneous helium vapor resulting from the heat load, created by the gimbals, 24 pusher/positioners and small OD, is utilized effectively in the cryostat heat shield which has an outlet temperature of 75K.

MAGNET STATUS	CRYOSTAT HELIUM FLOW DISTRIBUTION (l min <sup>-1</sup> )				TOTAL LIQ. He (l h <sup>-1</sup> )
	CURRENT LEADS (2)	CRYOSTAT SHIELD	TRANSFER LINE SHIELD	TOTAL FLOW	
UNPOWERED	160	50	160	370	29
(I) NOMINAL	220	60	180	460	36

Table 1. Cryogenic Operating Parameters

## PERFORMANCE

Three triplets, including one complete spare, were fully tested for almost a year, with their flexible transfer lines, and aligned on the pit floor adjacent to the beam line prior to installation.

All design criteria have been successfully satisfied. The triplets have been in almost continual operation since February 1991, with less than 10 hours beam downtime attributed to system malfunctions.

## ACKNOWLEDGMENTS

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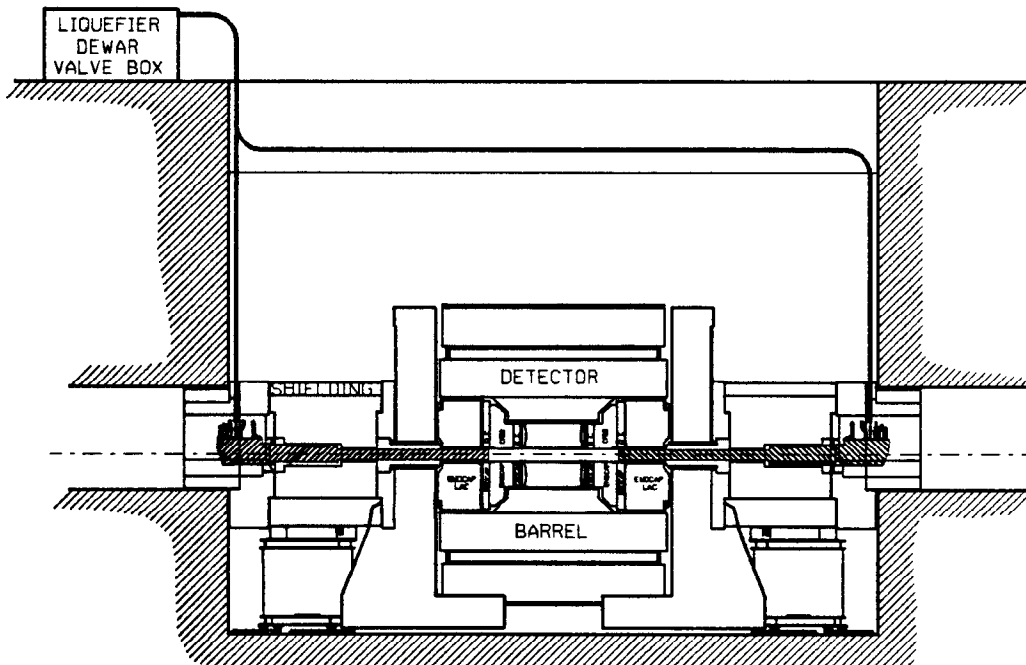


Figure 1. Triplet-detector layout.

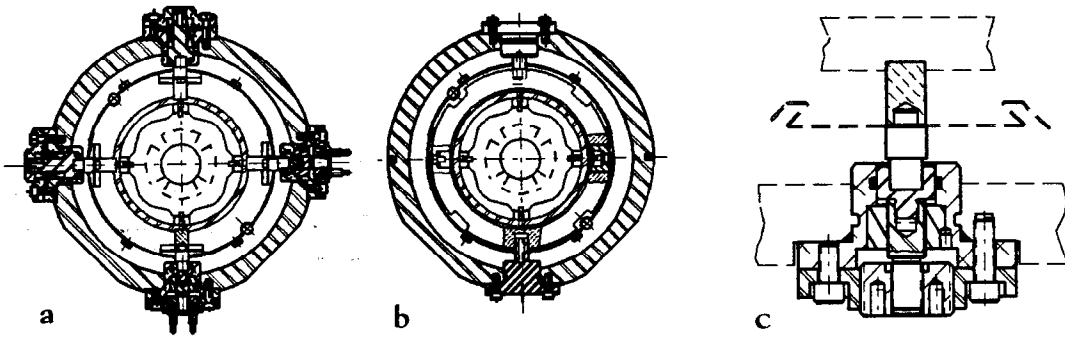


Figure 2. a) Adjuster-pusher; b) Gimbals; c) Screw adjuster.

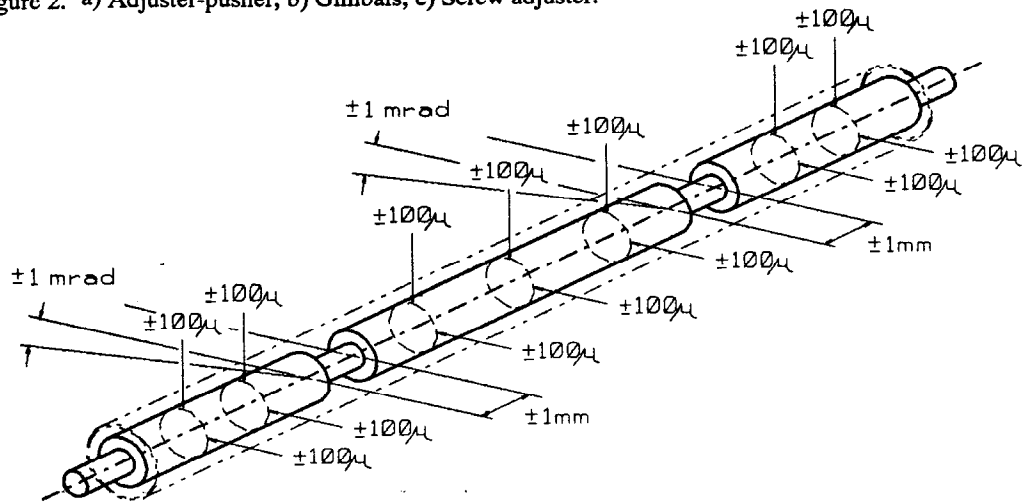


Figure 3. Static tolerances.

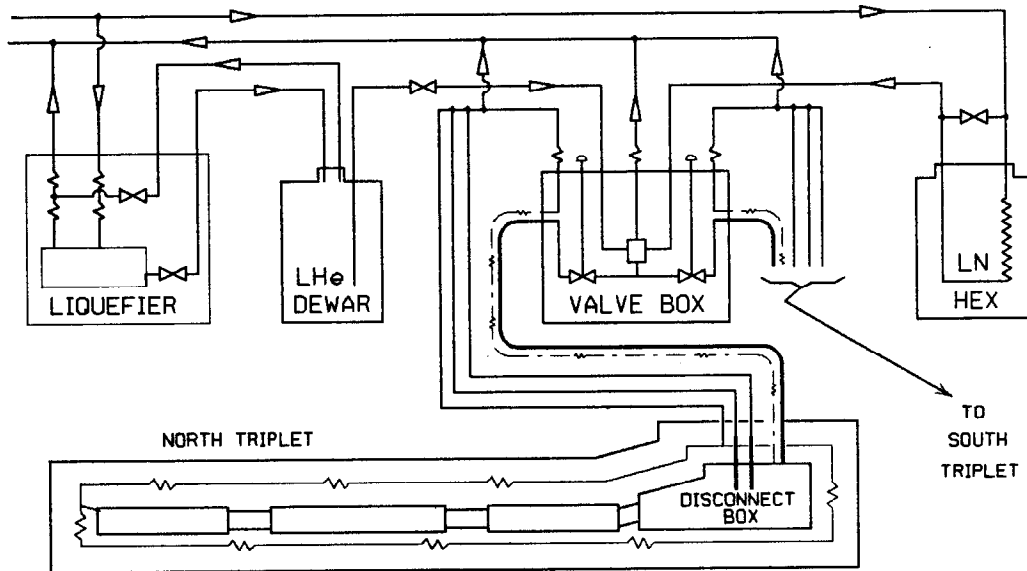


Figure 4. Cryogenic flow scheme.