Low Energy Bypass Line and Linac-to-Bypass/Bypass-to-Linac (LTB/BTL) Transfers

Requirements:

The low-energy bypass line must permit beams to be removed from the main linac at energies below the maximum design energy; the bypass line then transports these beams to the beginning of the beam delivery region, where they are returned to the nominal linac path for delivery to one of the interaction regions. The principal requirements on the bypass line are energy range (beam energies from approximately 43 GeV to 250 GeV must be accepted), emittance dilution (which must be minimal for all energies), and system cost (the bypass line may not add significantly to the cost of the main linac).

The Linac-to-Bypass (LTB) lines are the transfer lines from the main linac to the bypass line; there are three (four?) in each linac. The Bypass-to-Linac (BTL) transfer is a single line at the end of each linac which returns the beam to the main beamline for transport to the beam delivery system. The requirements on the LTB/BTL lines are similar to the requirements on the bypass line. An additional requirement is that the LTB/BTL lines must be compatible with eventual simultaneous operation of the two experiments; in this case, that implies that the design must be compatible with extraction of bunch trains on a linac-pulse by linac-pulse basis.

Technical description:

Overall Layout

The bypass line is a simple FODO array of under 100 quads per linac, which is parallel to the main linac and offset from it by approximately 30 cm in the horizontal. The quads are hybrid permanent magnet models; the quads have a maximum strength adjustment range of 20% (ie, they can be reduced 20% from their maximum), and the quads are identical (ie, the quad gradients are not tapered they way they are in the main linac; the design strength of all quads is identical). In addition, the bypass line contains a set of electromagnet matching quads at each LTB junction. All of the quads are envisioned to have a much larger bore than the main linac quads for ease of pumping. Also, the quad spacing of the bypass line has been adjusted to permit each bypass line quad to share a support with a main linac quad, in order to simplify the positioning of support piers: the piers which are to support a main linac quad and a bypass line quad can be “double-width” versions of the standard magnet support pier. The quad strengths are set to produce a lattice that becomes unstable (phase advance per cell > 180 degrees) for beam energies of approximately 43 GeV with the quads at nominal strength; the stable range can be increased to permit 35 GeV beams by use of the quad strength adjusters. Transport remains stable at all higher energies, with a phase advance per cell of 18 degrees at 250 GeV per beam.

Each main linac tunnel contains three (four?) LTB lines, placed at the 50 GeV, 125 GeV, and 250 GeV points in the main linac. Each LTB is an achromatic dogleg with two bend magnets (one at each end) and a short line of quads. Each LTB uses one linac quad and one bypass line quad as “combined function” magnets (ie, the beam goes off-axis through 1 main linac quad and 1 bypass line quad); the linac quad must have a larger bore
than the standard 0.5" to accommodate this. All LTB magnets are expected to be electromagnets, in order to permit the LTB optics to be matched to the beam energy (thus allowing the 50 GeV line to extract, for example, 45.6 GeV beams). Each main linac tunnel also contains one BTL transfer, which is a mirror-image of the 250 GeV/beam LTB.

Parameter table

Technical issues

The key technical issues for the bypass line and LTB/BTL are emittance dilution from synchrotron radiation and chromaticity; adequate matching; energy range; and radial envelope (since the linac and bypass line are placed side-by-side in the linac tunnel). In order to prevent mechanical interference between the LTB/BTL quads and the RF structures in the main linac, some additional length is required in the latter (ie, we need to drift the beam until the two beamlines have enough transverse separation to permit another RF structure). The total length required for 3 LTB lines and 1 BTL is approximately 200 meters per side.

In addition, the system design must be compatible with pulsed selection of beams for the bypass line. This implies that all vacuum connections for both linac and bypass operation must be made up at all times (ie, we cannot design a system in which connecting the bypass line implies breaking the connections in the linac, a la the ZDR-era IP Switch). It also implies that the LTB/BTL magnets must be pulsed bends, which appears feasible (fields on the order of 0.2 T are required, much lower than the SLAC 2-9 dump bend, which operates at almost 1 T and has a 120 Hz pulse rate). Since the pulsed operation will probably demand a small number of coil turns and thus a tremendous current pulse, it is envisioned that each bend will have both DC windings (many turns, low-current DC source) and pulsed windings (few turns, high-current pulsed source).

Pointers to subsystem docs

The 250 GeV/beam LTB (and, therefore, the BTL) is described in LCC-Note-0050.

Pointers to optics decks

The bypass lines decks are ebyp1.xsif, ebyp2.xsif, ebyp3.xsif; the LTB decks are eltb1.xsif, eltb2.xsif, and eltb3.xsif; the BTL deck is ebtl_250gev.xsif.

Open issues

The bend angles of the LTB/BTL lines are as large as feasible for emittance dilution (in order to minimize the “dead length” in the linac before another structure will fit); consequently the bend strength jitter must be limited (presumably by stringing all of the bends in one LTB/BTL on one power supply). In addition, if pulsed operation is desired the flatness of the pulse flat-top must be on the order of 80 parts per million over
the 300 nsec of the bunch train. It is not known whether such a tolerance can be achieved.

At the moment the bypass line does not contain diagnostics. Presumably a set of laser wire scanners would be required at each LTB to measure and correct the match into the bypass. One could imagine that as few as 3 wires per LTB (one at each of 3 consecutive QDs) would suffice, given that the phase advance per cell for emittance measurement is unfavorable only for a small energy region, and this phase advance (90 degrees per cell) can be avoided by judicious use of the quad strength adjusters.

Discussion of configuration choices

The demands on the bypass line itself are relatively simple and straightforward compared to practically any other accelerator system. Consequently the configuration choice—a long, sparse FODO lattice—was self-evident. The principal parameter of interest—the transverse distance between the bypass line and the linac—was a compromise between the expected tunnel diameter, ease of maintenance (which argues for a large offset), and length/complexity of LTB (which argues for a small offset). The 30 cm offset is believed to be adequate from all perspectives; although the bypass line will be harder to service than the main linac (the linac is on the aisle side of the tunnel), it has less components and is simpler and will require less arduous service.

LTB/BTL optics are a compromise between the requirements of achromaticity, a large bend angle (to minimize the impact on main linac length), and emittance dilution. A horizontal extraction is mandated by the main linac emittance ratio. As discussed above, the design appears to be an acceptable compromise, but the tolerance for bend-magnet matching (for DC operation) and/or pulse flat-top ripple (for pulsed operation) are nontrivial considerations. The former can be addressed by powering all bends in a given LTB/BTL in series on a moderately stable DC supply. The latter may not be so easily addressed: in order to make supply ripples cancel between the two sets of bend magnets, it would be necessary for the cable impedance to be well characterized, magnet inductances perfectly matched, a speed-of-light path for the magnet current between the first and second set of bends, etc.—in short, the task appears daunting. A more manageable solution might be to engineer the magnets to have a time constant which is long compared to 300 nsec but short compared to the minimum inter-pulse period foreseen (approximately 5 msec for 180 Hz operations). A significant challenge would be to even demonstrate on the test bench that the desired flatness had been achieved! However, we anticipate that for the small number of bend strings involved, the well-known technique of stacking R & D money on the magnet and power supply will yield adequate stability.