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IR Magnet Power Supplies

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Introduction

Because of the constraints imposed by low ß operation and injection on the IR optics, the required number of power supplies could be large. With variable phase trombones, minimal pairing of quads across the IR, and no shunt supplies, the required number of 6.6kA supplies is 126 for A. Garren's latest lattice design. The overall regulation requirement is still in the 10 ppm range which provides an interesting overall system design challenge. With this number of supplies, the IR's completely dominate the power supply cost and design effort. If it is possible to scale the lengths of the quadrupole magnets in the experimental insertions and in the phase trombones, impose a constant phase shift in each of these sections, and install low current shunts(< 4% in most cases and up to 20% in the case of QD4 and QD6), the number of required power supplies can be substantially reduced. This note summarizes the stages of this reduction. Figure 1 shows one side of an interaction region without the trombone.

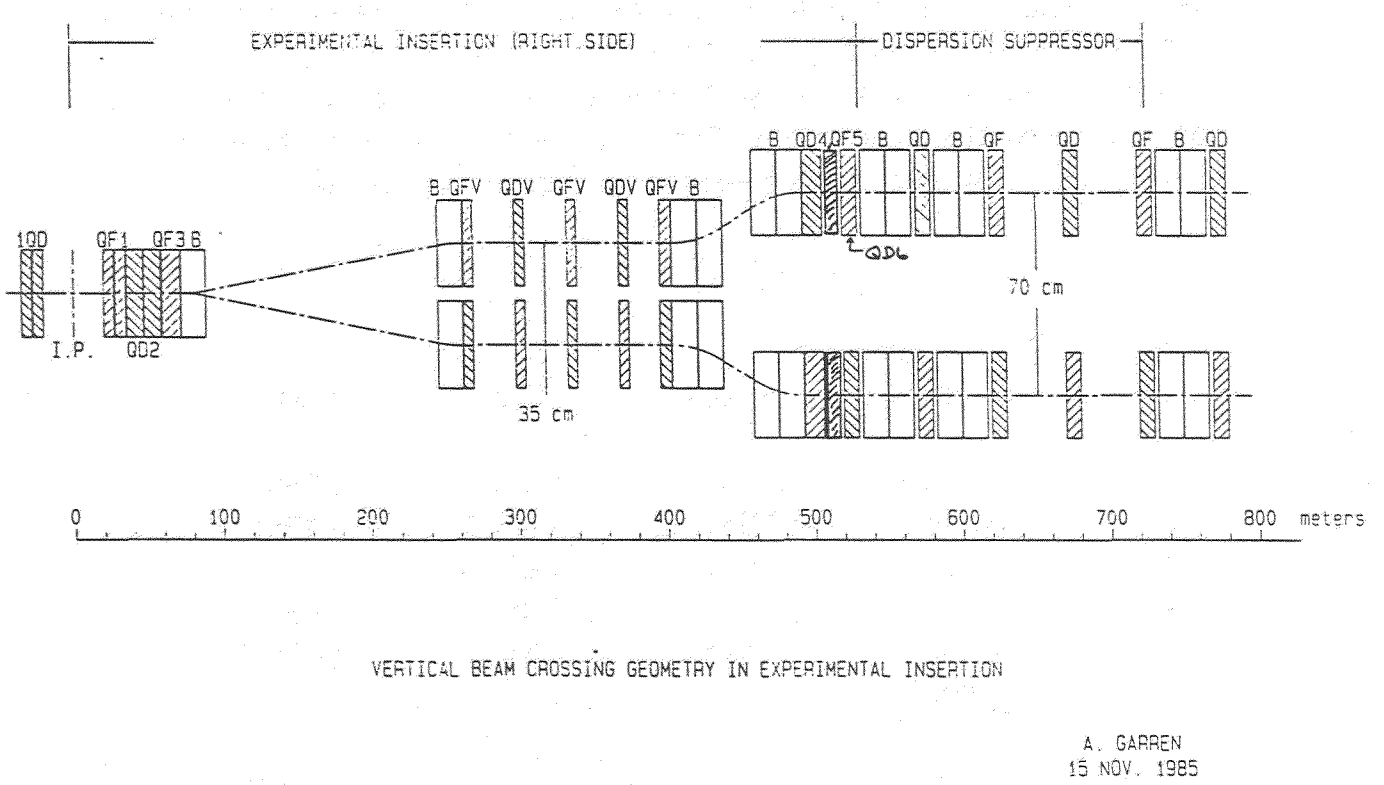

Figure 1. Vertical Section of an Experimental Insertion.

Variable vs Fixed Trombones

A. Garren's original lattice (Nov. 24) which uses fixed length quadrupole magnets and allows the phase advance to vary in both the experimental insertion and the phase trombone requires 6 power supplies per variable trombone. There are three of these variable trombones per ring leading to 36 power supplies for the trombones. With variable magnet lengths and trims, this can be reduced to 18. Recently, Al has begun exploring the possibility of holding the phase advance fixed in all the trombones which means they could be powered from the main bus with few percent trims to take care of tracking requirements. The initial results for $\beta^* = 1$m to 5m are very encouraging and it looks like it will be possible to eliminate the variable trombones. This eliminates the need for the 18 power supplies.

IR Experimental Insertion

The IR insertion is characterized by a triplet just outside the interaction point followed by the m = -1 section followed by a second triplet after which comes the dispersion suppressor which matches into the regular arc lattice. From the power supply point of view, the vertical bends, the m = -1 section, and the dispersion suppressor are powered by the main magnet bus. This leaves the two triplets to be powered. The pattern is repeated on the other side of the interaction point. Table 1 summarizes the k's, in Al Garren's notation, required for the different operating conditions and modes. For our purposes, k is proportional to magnet current scaled by the operating energy of the collider.

Table 1. IR Triplet k Values

Quad No.	$\beta^* = 1$ m		$\beta^* = 5$ m	
	Var.	Fixed	Var.	Fixed
1	3.5834	3.5834	3.5265	3.5401
2	-3.5517	-3.5517	-3.4769	-3.4562
3	3.5370	3.5370	3.4185	3.4061
4	0.1678	0.1678	3.4897	3.4969
5	-2.4987	-2.4987	-4.8425	-4.8051
6	0.8022	0.8022	3.9267	3.9152

All table entries are multiplied by 10^{-3} in A. Garren's units.

As can be seen from the table, the inner triplet has less than a 3% variation in current in moving from the injection lattice ($\beta^* = 5$ m) to the interaction lattice ($\beta^* = 1$ m). This level of variation is easily accommodated with a trim shunt supply. Further, if the lengths of the magnets are tailored to the k values desired and jumpers installed across the interaction point, the inner triplets can be operated from the main magnet bus and two or four low current trim shunt supplies depending on jumper costs versus trim shunt supply costs.

The outer triplet is more complicated because of the much larger current swing in going from the injection lattice to the interaction lattice. If a current shunt with a capacity of 20% of the maximum current is permitted, then Q4 and Q6 can be connected in series and powered by a common supply with a 20% shunt bypassing Q4. Q5 must be independently powered. It is probably cheaper to provide separate power supplies for the outer triplets on either side of the interaction point because of their 1km separation.

IR's as a Single Ring?

The concept of two independent rings in the interaction regions has already been seriously tarnished by the fact that both rings share the inner triplets at the interaction point and the m = - 1 insertion magnets are in a common cryostat. At this point, it makes little sense to insist on powering the m = -1 insertion magnets from their corresponding ring magnet bus. If instead, they are powered from one of the buses there is a substantial saving in bus work in this congested area. If we expand this single ring philosophy to include the outer triplet, we can save another factor of two in power supplies for these triplets.

Conclusion

If we are willing to impose the constant phase condition on the trombones, use few % trims on the inner triplet, tailor magnet lengths to desired k values, and operate the experimental insertions as a single ring, the number of 6.6kA well regulated supplies can be reduced from the 126 required for the full flexibility lattice to 24 for the constrained lattice. The savings in high current leads alone is more that $5M with probably more than a $10M savings in power supply costs. There are also considerable cost savings in the energy extraction system associated with the quench protection system. Each supply must provide about 40kW to room temperature energy dump switches, leads, and filters at full current. The operational reliability of the collider will be improved by a reduction of a factor of three in the high current power supply count.