A Proposal for Booster Lattice Modification

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Abstract
This note describes ways the Booster lattice can be modified or replaced. The aim is to create long straight sections for injection and extraction while also avoiding transition crossing. Reusing some number of main magnets and using them as spares is additional guiding principle in search for better lattice.

Introduction

Presently, the Fermilab Proton Source can deliver ~5x10^{12} of protons per 15Hz pulse and its intensity is limited by space charge at injection to the Booster and by beam losses. The planned improvements include RF cavity refurbishment, 20Hz upgrade and new CW SRF linac. The beam injected in the Booster will be an H- beam with a kinetic energy of ~ 1 GeV. To fully utilize planned improvements and increase the beam power output we consider the possibility of redesigning the Booster lattice. The assumption being that we will keep using the exiting tunnel.

Modified Lattice

Present Booster lattice is 24- fold symmetric with ~6 meter long straight sections.

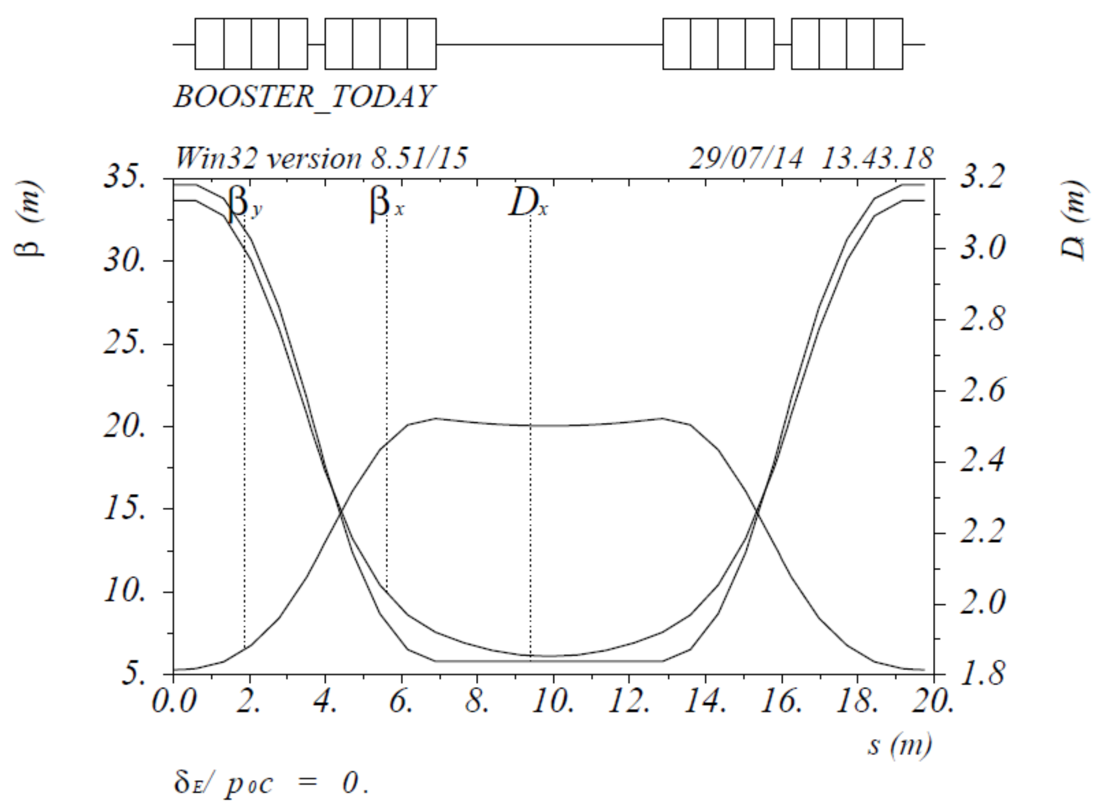


Figure 1. Present Booster lattice functions.
total length = 19.750700 Qx = 0.279385 Qy=0.281807 gamma(tr)= 5.452312
betax(max) = 33.65 betay(max) = 20.49 Dx(max) = 3.18 Dy(max)=0.0000

The tunnel is 24 symmetric and allows for a ring with minimal 12 fold symmetry. One possibility is to have a lattice with six super periods, with very long straight sections.

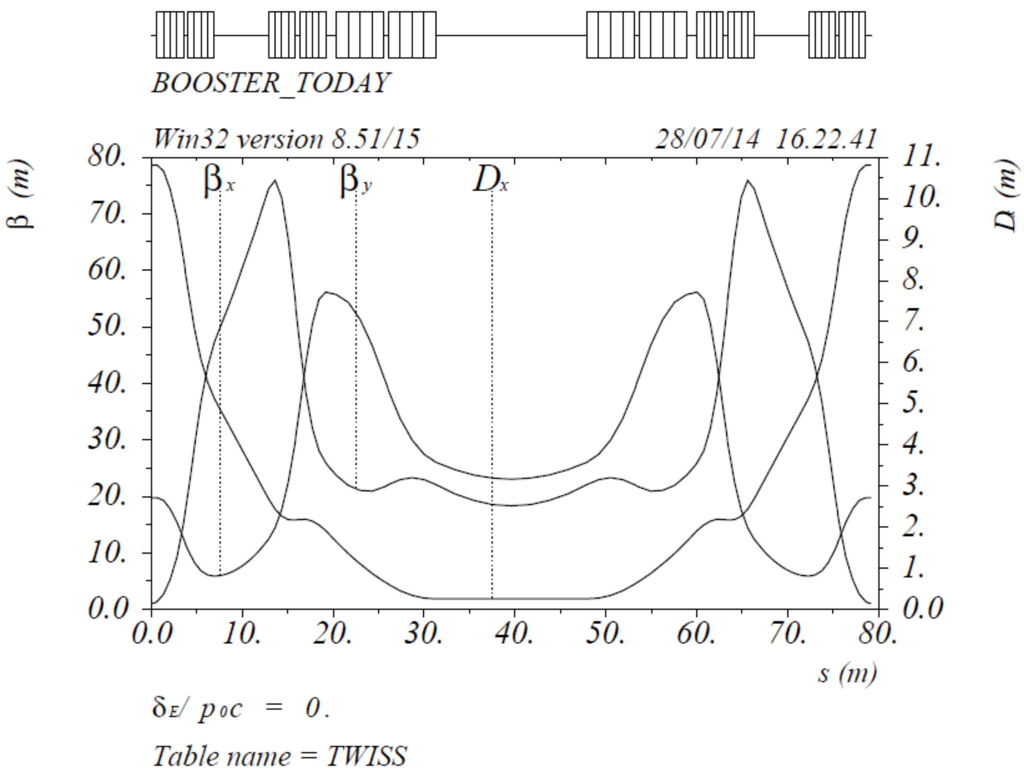


Figure 2.

total length = 474.261336 Qx = 4.5463 Qy=4.8974 gamma(tr) =5.050255
betax(max) = 57.33 betay(max) = 67.08 Dx(max) =10.58 Dy(max) =0.0

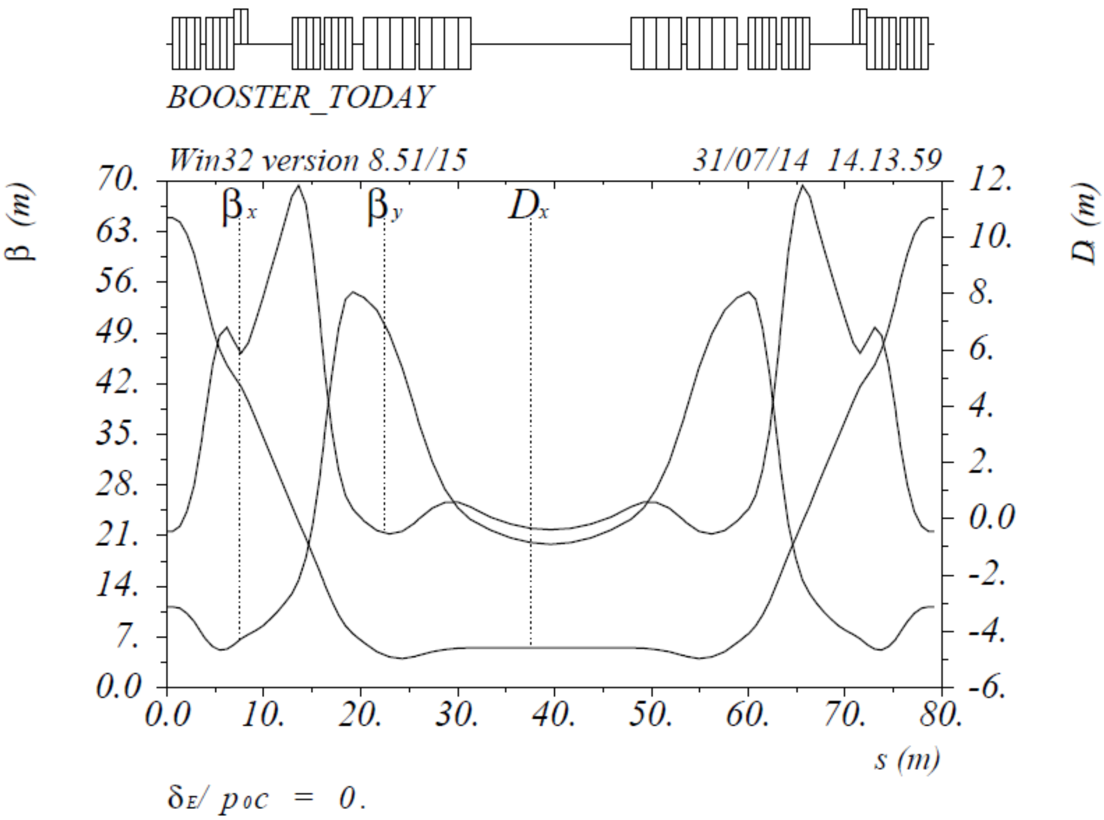
Figure 2 shows the lattice function of one super period. This is a partially changed Booster lattice. In this lattice, four Booster cells are replaced with a single super cell made of one long cell sandwiched between two regular Booster cells. Adopting these changes in the ring we will:

- replace half of the existing magnets with 24 new magnets,
- create six, ~15 meters long straight sections,
- have almost zero dispersion in long straight sections, Dx=0.25m
- have an almost round beam in long straight sections
- have space for six Booster cavities in long straight section
- have a 15 meter long free space for injection and extraction

The disadvantage of this lattice is that the transition energy is still in the middle of acceleration range, and larger beta function than in the existing Booster.

Lattice with Imaginary Transition

Now that the lattice has six very long straight sections, straights in the regular Booster cells are free to be used for positioning other elements. One way of using them is to create a lattice without transitions. If we introduce a strong quad (k=0.06, 1.5 meter long) in the long strait of Booster regular cell, we can create a lattice with imaginary transition.



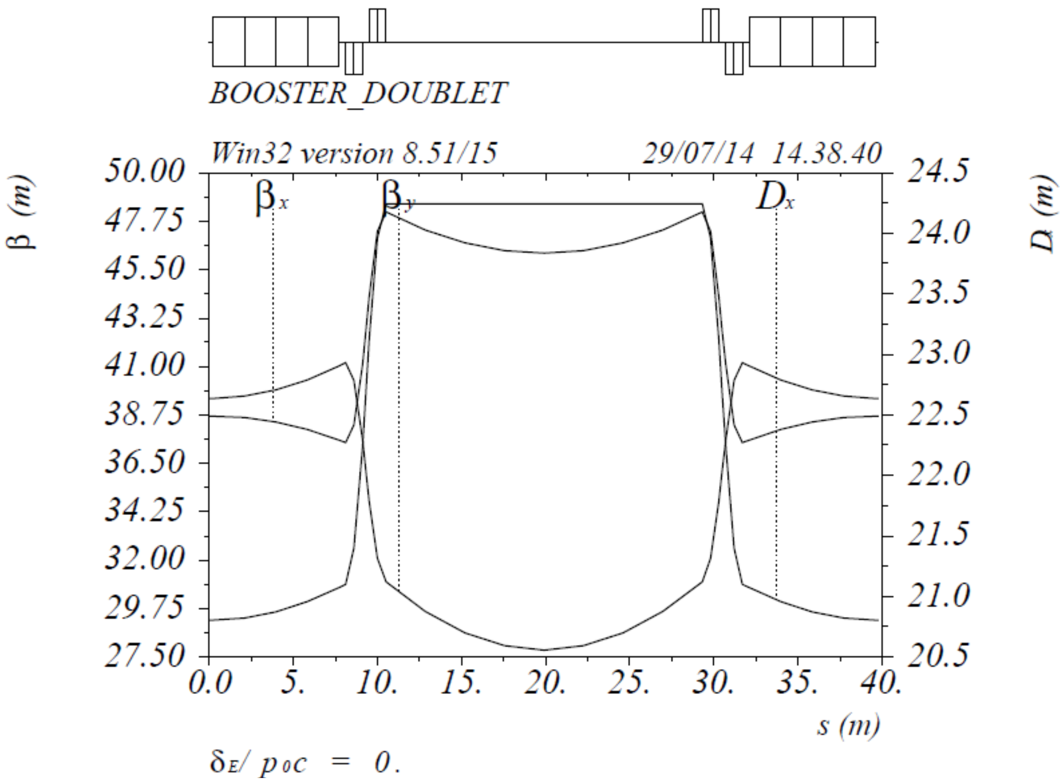
total length = 79.198601 Qx=0.828899 Qy=0.434477 gamma(tr) = -9.392635
betax(max)= 54.63 betay(max) =69.36 Dx(max)=10.68

This lattice has an extra twelve quadrupoles but avoiding transitions make this lattice very attractive. The lattice functions are larger than in the present Booster but reasonable.

Lattice above Transition

Another possibility that we have analyzed is a lattice with transition energy below injection energy. This lattice contains twelve identical cells, with 24 dipoles and 48 quadrupoles.

The long straight section is ~ 19 meter long and maximal dipole field is less than 1T. The quads are 1 meter long with k~0.1 m^{-2}.



total length = 477.60 Qx=1.789870 Qy=2.272460 gamma(tr) =1.907276
betax(max) = 48.17 betay(max)= 41.17 Dx(max) = 24.24 Dy(max)=0.0

This is a 12-fold lattice. As presented here, this is a separate function lattice, but a defocusing quad can be imbedded in the dipole magnet and reduce the number of lattice elements.

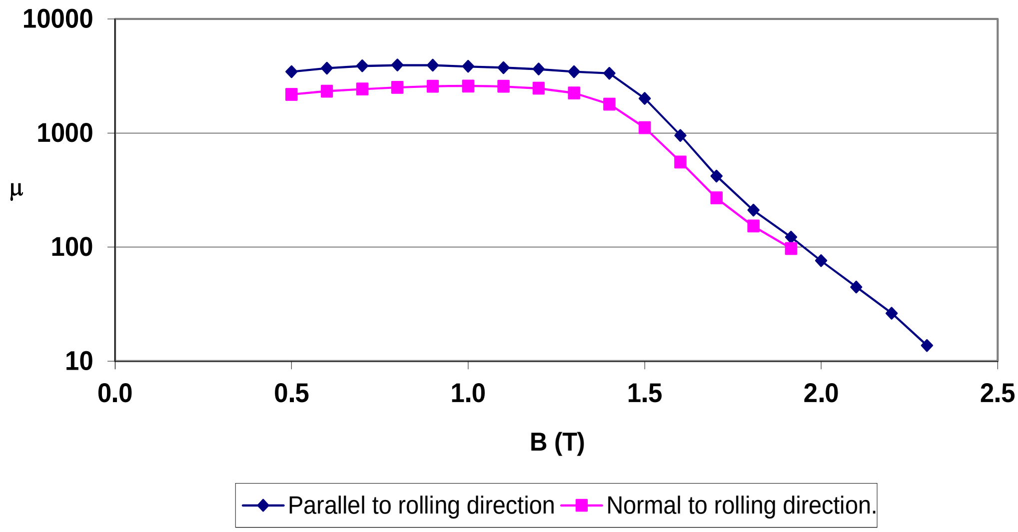
The main advantage of this lattice is that the beam does not go through transition, straight sections are very long, and relatively small number of dipoles (24) and quads (48). To have these properties we had to increase horizontal dispersion of the ring. The assumption is that the beam will have a relatively small momentum spread, $\sim 10^{-3}$. In any case, this ring will need to have a large beam to avoid problems with space charge at injection with a small emittance beam.

Conclusion

Table below lists elements of the presented lattices, number of different elements and basic parameters.

	Booster	Lattice1(γ_T=5.0)	Lattice2(γ_T=Img)	Lattice3(γ_T=1.9)
Magnet(L~2.98m Ang~3.7 K~0.05m^{-2})	96	48	48	
Magnet(L~7.5m Ang~7.5 K~0.01m^{-2})		24	24	
Dipole				24
Quad			12(L~1.5m,k~0.02m^{-2})	48(L~1m,k~0.1m^{-2})
VLongStr		6(L~15m)	6(L~15m)	12(L~19m)
LongStr	24(L~6m)	12(L~6m)	12(L~4m)	

These three presented lattices are just examples how the Booster ring can be modified. All magnets used in presented lattices have a maximal magnetic field less than 0.9T. This requirement was imposed to avoid saturation and reduce power loss during rump. This can be relaxed because the data shows that the relative mu for silicon steel can be increased just following rolling orientation, see Figure 4. One attractive variation of lattices described here that will be considered part of the ring has been built out of permanent magnets.
This is based on the observation that Booster ring can be modified and the permanent end electrical magnets separated.



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The rest is irrelevant.