A Proton Driver for the Muon Collider Source with a Tunable Momentum Compaction Lattice *

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Abstract

The future Muon Collider will have a luminosity of the order of 10^{35} cm^{-2-1} during 1000 turns when the muons decay. This requires 10^{12} muons per bunch. The muon source is a 30 GeV proton driver with $2.5\ 10^{13}$ protons per pulse. The proton bunch length should be of the order of 1 ns. Short bunches could be created by a tunable momentum compaction lattice which would bring the momentum compaction to zero in a short time. This isochronous condition would allow bunches to shear and become very short in time. We present a lattice where the momentum compaction is a tunable parameter at fixed horizontal and vertical betatron tunes. The values of the maxima of the dispersion function are kept small. We examine two kinds of lattices, with combined function as well as normal dipole and quadrupole magnets.

1 INTRODUCTION

The muon collider progress report and its components are described in other reports at these proceedings [2], [3], [4], [5] etc. Muons will be created through pion decay. The proton driver, a high intensity ~30 GeV synchrotron, delivers compressed and focused bunches to a heavy metal target, generating pions which are captured and transfered to a linac. The proton bunches need to be very short (of the order of 1 ns) to minimize the final muon longitudinal phase space and reduce the cost of the muon phase rotation section. It is very desirable to have a proton synchrotron without transition crossing and with *tunable* momentum compaction α. RF manipulations could be performed very easily if the momentum compaction is adjustable, but this requires unchanged betatron tunes. A finite synchrotron frequency is preferable for stability. There have been many previous reports on *harmonic modulation* of the lattice [6] [7], a *missing dipole* approach by U. Wienands [8] and the a recent report by B. Autin [9]. We reported earlier a *flexible momentum compaction* (FMC) approach [10] which represents a possible solution for the design of such a lattice. Because the Proton Driver would require fast acceleration and a lot of cavities, the *missing dipole* solution for momentum compaction control looks very preferable. The drawback is dispersion in the cavities. We report a lattice design method which uses the FMC modules with *missing dipoles*in a standard FODO cell lattice, to make the momentum compaction tunable. With small adjustments of the quadrupoles on both sides of the missing dipoles in the FMC module the transition energy γ_t may be changed to any desired value without changing the betatron tunes.

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2 THE *MISSING DIPOLE* CELL

Three standard FODO cells are used to produce an imaginary γ_t lattice by having two dipoles missing within the central cell, as previously reported [8]. The length of the

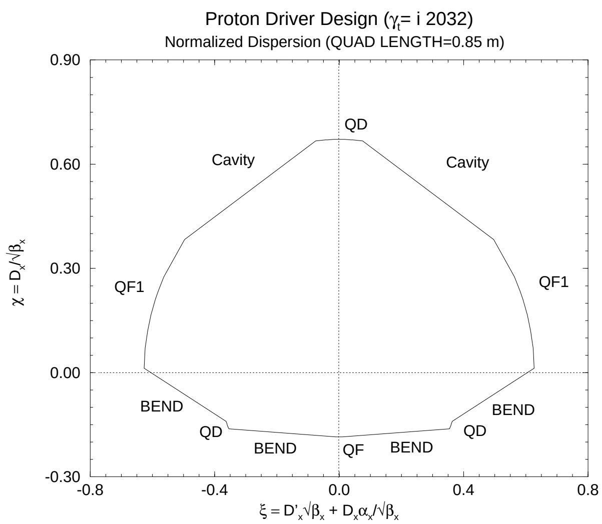

Figure 1: Imaginary γ_t lattice with *missing dipole* FODO cells lattice.

cell is selected by setting the limit on a dipole magnetic field strength to B~1 T [11]. The betatron functions have maxima of β_x=27.1 m and β_y=27.8 m, with an imaginary transition energy of γ_t=i 2032. The "FMC-method" of lattice design, described earlier [12], uses the normalized dispersion function. The *Missing Dipole* FODO lattice, tuned to be an imaginary γ_t lattice, is presented in normalized dispersion space in Figure 1. The middle FODO cell without dipoles is shown in the upper part of the ξ and χ diagram where the dispersion is positive. The oscillations of the dispersion function are within a range from D_{max}=1.42 m to D_{min}=-1.00 m. The dispersion values in the regular 90^o FODO cell, made of the same elements, oscillates between from D_{max}=1.39 m to D_{min}=0.68 m. The betatron functions of the *missing dipole* FODO cells are presented in Figure 2. There are many synchrotrons still in operation today (AGS at Brookhaven National Laboratory, Fermilab Booster, PS at CERN, etc.) which were built with combined function magnets. The same method of lattice design is applied with combined function dipole FODO cells in Figure 3. The betatron functions have little different maxima β_x=22.2 m and β_y=41.9 m and the dispersion function

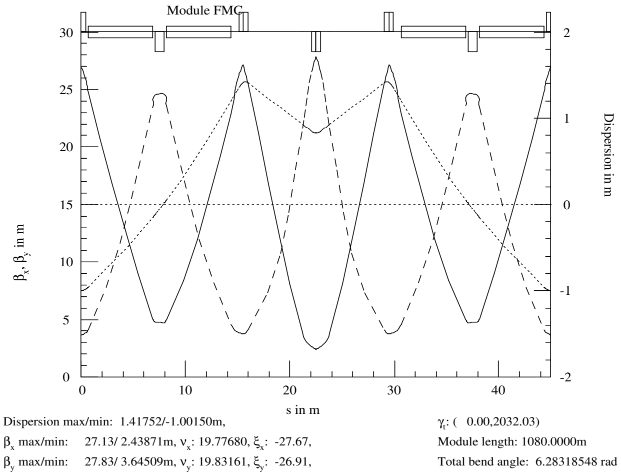

Figure 2: Imaginary γ_t lattice with *missing dipole* FODO cells.

oscillates from D_{max}=1.49 m to D_{min}=-0.85 m.

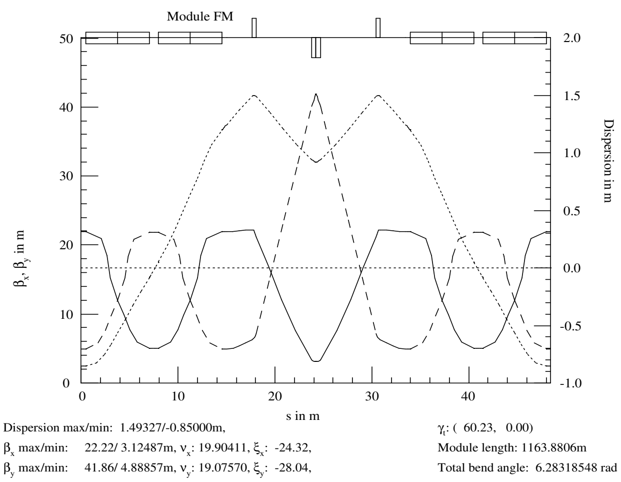

Figure 3: The *missing dipole* FODO cell lattice with combined function dipoles.

3 TUNABLE MOMENTUM COMPACTION WITH *MISSING DIPOLE* FODO CELLS LATTICE

The horizontal and vertical betatron tunes have to remain unchanged if the momentum compaction of the accelerator is required to change during the operation. This was an additional constraint to the design. We have demonstrated [10] that the momentum compaction of a *Flexible Momentum Compaction* module can be adjusted to almost any value by choosing the value of the minimum dispersion function at the beginning of the module and adjusting the gradients of the quadrupoles. The length of the FMC module was kept constant. The momentum compaction dependence on the value of the minimum dispersion function in a different FMC module is presented in Figure 4. A very similar quad and the minimum of the dispersion function adjustments in these *missing dipole* FODO cells are

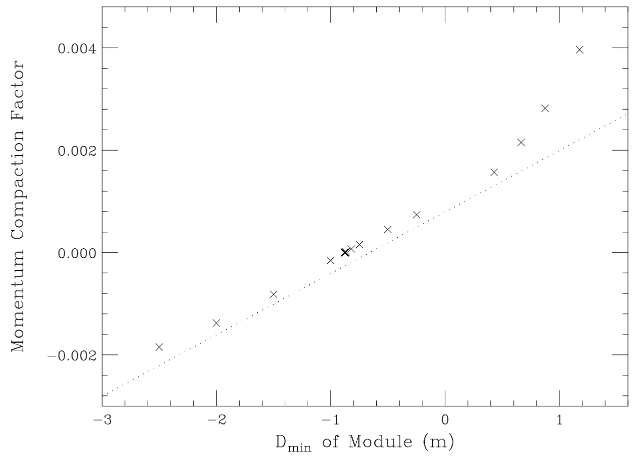

Figure 4: The momentum compaction α dependence on the initial negative value of the dispersion function in a different FMC module.

performed (see Table 2). First, positions of the focusing quadrupoles QF1 in the central FODO cell were allowed to be a variable parameter, keeping a constant length of the FODO cell as well as the horizontal and vertical betatron tunes. The quadrupoles length was selected [11] to be L=0.85 m. A distance of the focusing quad with respect to the end of the dipole is labeled D1, while the other side towards the RF cavity is D2.

Table 1

D1(m)	D2(m)	α	D_{min}	D_{max}
0.567	1.041	0.0004110	-0.88	1.442
0.654	0.955	0.0001770	-0.81	1.428
0.679	0.929	0.0001100	-0.97	1.425
0.692	0.916	0.0007659	-0.98	1.423
0.706	0.902	0.0000408	-0.99	1.420
0.721	0.888	0.0000048	-1.00	1.418
0.723	0.886	0.0000000	-1.00	1.417
0.734	0.874	-0.0000297	-1.01	1.416
0.761	0.848	-0.0000978	-1.03	1.411
0.808	0.800	-0.0002106	-1.06	1.402
0.839	0.769	-0.0002884	-1.08	1.397

A positions of the focusing quadrupole QF1 is selected at the isochronous condition (or when α=0). A solution, for the tunable momentum compaction for the *missing dipoles* FODO cells, was found by splitting the focusing QF1 quadrupoles into two new QFS and QF2 quadrupoles, at the beginning and the end of the central FODO cell with missing dipoles. The betatron functions within the momentum compaction tunable lattice are presented in Figure 5. The momentum compaction was tunable by adjusting gradient values in the two new quadrupoles as presented in Table 2. The dispersion values presented in table 1 are in meters. It is important to note, The betatron tunes values at all quadrupole settings for the corresponding γ_t values were kept within an error of $\leq 10^{-4}$.

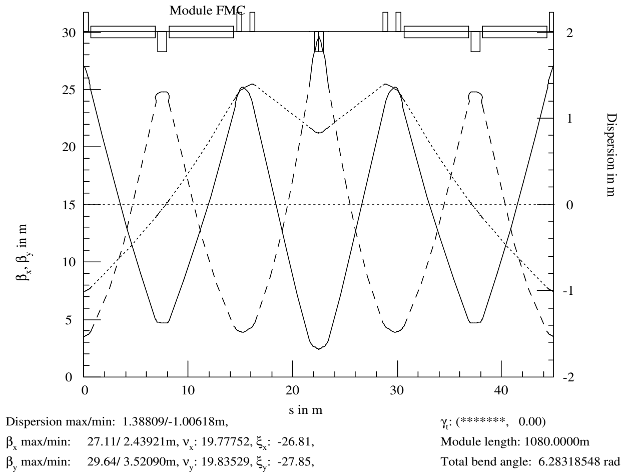

Figure 5: The *missing dipole* FODO cell lattice with tunable momentum compaction.

Table 2

GFS(T/m)	GF2(T/m)	α	D_{min}	D_{max}
12.89	38.60	0.000424	-0.88	1.43
17.23	35.36	0.000191	-0.81	1.41
19.52	33.56	0.000021	-0.86	1.41
20.49	32.77	0.000001	-0.88	1.40
27.23	27.08	0.000000	-1.01	1.39
27.28	27.04	0.000003	-1.01	1.39
27.50	26.85	0.000015	-1.01	1.39
32.93	21.93	0.000335	-1.10	1.37

Table 2 shows the dependence of the transition energy γ_t on the gradients in the two quads. More details of this is shown in Figure 6.

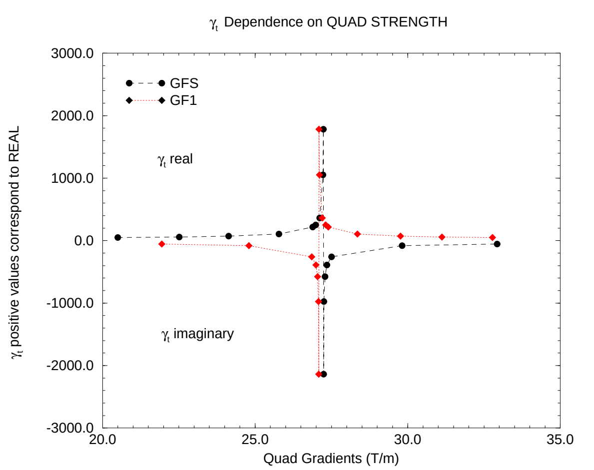

Figure 6: Transition energy, γ_t, dependence on the quad gradients.

4 CONCLUSIONS

The proton driver for the muon collider requires very short bunches of the order of 1 ns. The proton driver is a fast cycling machine which requires a lot of RF cavities distributed around the ring. This is why the *missing dipole* FODO lattice design was combined with the *Flexible Momentum Compaction* method. The drawback of this design is not having zero dispersion at the cavities. An abrupt change of the momentum compaction at the end of the accelerating cycle, would shear the bunches and make them very narrow in time but wide in momentum. A lattice with a tunable momentum compaction, fulfilling this condition, keeps the dispersion function within small values in the range of D$\approx$ $\pm$1m to allow a large momentum aperture. This lattice might be also suitable for RF manipulations, where instead of the RF frequency change one can use the tunable momentum compaction. An experiment at the AGS to examine the creation of short bunches by a sudden change in momentum compaction has been proposed and accepted. This experiment will be performed at the transition energy by using the γ_t quadrupoles to produce a required difference in the momentum compaction.

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