Optimum Muon Acceleration FFAG Lattices without Time of Flight Constraints

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In designing a muon FFAG, one important design constraint is to make the time-of-flight variation sufficiently small. However, if one is able to vary the RF frequency, one can in principle eliminate this constraint. I compute optimized designs for muon FFAGs which have no constraint on the time of flight, and compare them to muon FFAGs which do have that constraint.

I. INTRODUCTION

In [1], I describe a method for finding an optimum design for an FFAG for muon acceleration. Since the time of flight in an FFAG depends on energy, if one accelerates too slowly, the bunch will eventually leave the RF crest and no longer be accelerated. To achieve a given longitudinal transmission, one must have a sufficiently large value of the quantity $a = V/(\omega\Delta T\Delta E)$, where V is the voltage in the ring, ΔT is the range in the time of flight (see [1] for a precise definition), ΔE is the energy range, and ω is the angular RF frequency.

However, if one is able to vary the RF frequency during the acceleration cycle, one can correct for the time of flight variation with energy by varying the RF frequency. To determine whether exploring this option would be worthwhile, one should determine the cost saving that would be realized by using such a scheme. Thus, I will change the procedure described in [1] to remove the constraint on the time of flight, producing a new set of cost optimized designs.

II. RESULTS

For reference, the designs which are optimized including the constraint on the time of flight are given in Tab. I. The designs without the constraint on the time of flight are shown in Tab. II. All of the calculations assume 17 MV/m cavities, and a decay cost of 5 PB/%.

The time of flight as a function of energy for the three optimized lattices is shown in Fig. 1. The range in time of flight shown there requires a range of relative frequency variation of around 5.4×10^{-3}, 2.8×10^{-3}, and 1.3×10^{-3} for the 2.5–5, 5–10, and 10–20 GeV lattices respectively. These variations must occur in about 2, 5, and 12 μs respectively.

The rings become shorter, resulting in an increased magnet cost (due to a larger magnet aperture [1]). There is a reduced RF cost due to more passes being made through the RF. Despite the assumption that the bunches are always on the RF crest in the case where time of flight is ignored, there is more decay in that case, since the lattice cells are longer, giving a reduced real-estate RF gradient. If running on-crest increased the RF system cost by less than about 20%, there would be a cost advantage in doing so.

TABLE I: Lattice designs optimized with a constraint on the time of flight.

Minimum total energy (GeV)	2.5	5	10
Maximum total energy (GeV)	5	10	20
$V/(\omega\Delta T\Delta E)$	1/6	1/8	1/12
No. of cells	50	65	82
D length (cm)	63	77	97
D radius (cm)	13.4	10.0	7.4
D pole tip field (T)	4.5	5.7	7.1
F length (cm)	96	113	141
F radius (cm)	21.2	16.3	13.1
F pole tip field (T)	2.7	3.5	4.3
No. of cavities	58	49	56
RF voltage (MV)	534	620	704
Turns	4.7	8.2	15.0
Circumference (m)	204	286	400
Decay (%)	4.2	5.1	6.5
Magnet cost (PB)	39.4	37.2	39.1
RF cost (PB)	30.3	35.2	39.9
Linear cost (PB)	5.1	7.2	10.0
Machine cost (PB)	74.8	79.5	88.9

The 20% cost increase limit refers to the entire RF system (cavity, cryostat, and power). However, since the beam is in the cavity for only a small fraction of a cavity fill time, the power source does not need modification. Thus, the only system that needs to be added is something that will shift the resonant frequency of the cavity by the amounts in the times shown above. This can be very challenging, since the cavities are 200 MHz superconducting cavities.

One might consider trying to improve the real-estate gradient by using two-cell cavities instead of single cell cavities. This does not end up helping since the longer RF drift and longer magnets that are required work against you, and the decays end up being even worse.

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TABLE II: Lattice designs optimized with no constraint on the time of flight.

Minimum total energy (GeV)	2.5	5	10
Maximum total energy (GeV)	5	10	20
No. of cells	38	47	65
D length (cm)	84	102	119
D radius (cm)	13.3	10.1	7.6
D pole tip field (T)	5.1	6.5	7.9
F length (cm)	113	143	171
F radius (cm)	23.4	19.7	15.2
F pole tip field (T)	3.2	3.8	4.6
No. of cavities	30	36	45
RF voltage (MV)	380	464	566
Turns	6.6	10.8	17.7
Circumference (m)	169	232	350
Decay (%)	4.8	5.4	6.6
Magnet cost (PB)	40.0	40.6	42.7
RF cost (PB)	21.5	26.3	32.1
Linear cost (PB)	4.2	5.8	8.8
Machine cost (PB)	65.7	72.8	83.6
Extra decay cost (PB)	3.1	1.5	1.0
Cost reduction (%)	8.0	6.6	4.9

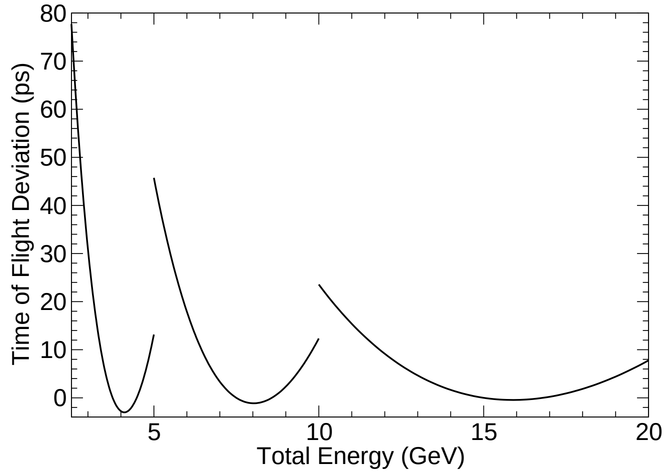

FIG. 1: Time of flight as a function of energy for the lattices without time of flight constraints.

III. ACKNOWLEDGMENTS

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[1] J. Scott Berg, "Recent Results from Optimization Studies of Linear Non-Scaling FFAGs for Muon Acceleration," to appear in the proceedings of FFAG 04, KEK, Tsukuba, Japan, 13–16 October 2004. Preprint MUC-CONF-ACCELERATION-390, `http://www-mucool.fnal.gov/notes/notes.html`.