MEASUREMENTS AND CORRECTIONS OF THE RECYCLER LATTICE AT FERMILAB*

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Abstract

The lattice measurement has been done several times by taking differential orbit measurements and fitting the data with Orbit Response Matrix(ORM) to calibrate linear optics in the Recycler ring at Fermilab. Large beta-wave (~20%) was found in horizontal plane after the working point was moved for the reason of lowering the beam instabilities. The source of the beta-wave, and the correction of the lattice will be presented in this paper. In addition, we found a easy way to extend the tuning range in the Recycler lattice. The results will be presented in this too.

LATTICE MEASUREMENTS

Orbit Response Matrix (ORM) method has been successfully used to calibrate the linear optics of the Recycler Ring at Fermilab [1]. Lattice functions obtained from LOCO (Linear Optics from Closed Orbit) fitting using large number of differential orbit data were performed several times. The first orbit response measurement was done in Oct. 2005 and a full set of data consisting of roughly 150 differential orbits was taken at the working point (25.424, 24.434), the beta-functions obtained are shown in Fig. 1(a). Compared to the designed lattice, we see a very little beta-wave in the plot, although the relative beta function errors are up to 40% in horizontal and 20% in vertical. During 2006 Summer Shutdown, we did some magnet moves in the ring to reduce the strengths of some correctors. We also moved the working point tunes from (0.424, 0.434) to (0.456, 0.467), primarily for the reason of lowering the beam instability during the anti-proton mining process. We repeated the orbit response measurement with more than 200 the differential orbits taken, and the obtained beta-functions from this measurement are shown in Fig. 1(b). We see a very large beta-wave in horizontal plane.

The source of the beta-wave was tracked down to the phase trombone section. The Recycler ring is an 8-GeV fixed energy ring using permanent magnets [2]. Instead of distributing remotely adjustable quadruples around the ring, 9 pairs of independently power supplied trim quadruples are located in RR-60 straight section and used to adjust the tunes. It is called the phase trombone section, as seen Fig. 2. The principle of the trombone section is to adjust the phase advances, i.e. tunes in the ring, but keeping the beta-functions unchanged at two ends at MRK601 and MRK609, as shown in Fig. 2.

If all the currents of 9 pairs of trim quads are set to 0, the measured tunes are (25.414, 24.430). A console application program TROMBONE has been used operationally for tuning up the tunes to the working point. In March 2004, program TROMBONE was migrated based on designed lattice functions, and to maintain a symmetrical structure, 9 quadruple circuits were segmented into 5 families [3].

From the lattice measurement, we know that beta-functions at 2 ends of the trombone section are different significantly from the designed values, as listed in Table 1. Therefore, it is necessary to update the trombone program based on measured beta-functions. The reason that we don't see too much beta-wave at old working point is probably the currents needed in 9 quad circuits are relatively small, resulting in small beta function leak from the trombone section.

Table 1: Beta-functions at MRK601 and MRK609

Beta-functions		β_{x1}	β_{y1}	α_{x1}	α_{y1}
Designed lattice	@601	**10.103**	**46.958**	**-0.098**	**0.014**
	@609	**10.114**	**46.367**	**0.008**	**0.012**
Measurement	@601	**8.733**	**8.016**	**-0.099**	**0.047**
	@609	**8.683**	**47.815**	**-0.063**	**0.33**

CORRECTIONS

We know that each of 9 pairs of quadruples in RR-60 straight section has their own power supply. In principle, each of them can be adjusted independently as long as keeping the conditions that the Twiss parameters at the two ends of the straight section unchanged. The detailed matching conditions can be seen in Ref [3]. A test TROMBONE program was written in MATHEMATICA using measured beta-functions. The general equations are obtained for keeping 9 variables in the role. For a given tune changes, the equations can be solved by SVD (Singular Value Decomposition). We found that all the currents are reasonably, evenly distributed if the currents of 9 circuits are independently adjusted. For example, to get to the current working point, the given tune change would be ν_x =0.0385, ν_y=0.042, the currents of 9 circuits were calculated as follows (unit in Amps):

I1,I2,…,I9 = (-1.300, 1.823, -1.810, 1.707, -1.248, 1.561, -1.859, 1.940, -1.229)

Therefore, the console application program TROMBONE was upgraded followed the same algorithm as in the test program in MATHEMATICA. Given a tune change, program TROMBONE gives a set of quadruple currents, which will be sent to hardware. Using Schottky detector,

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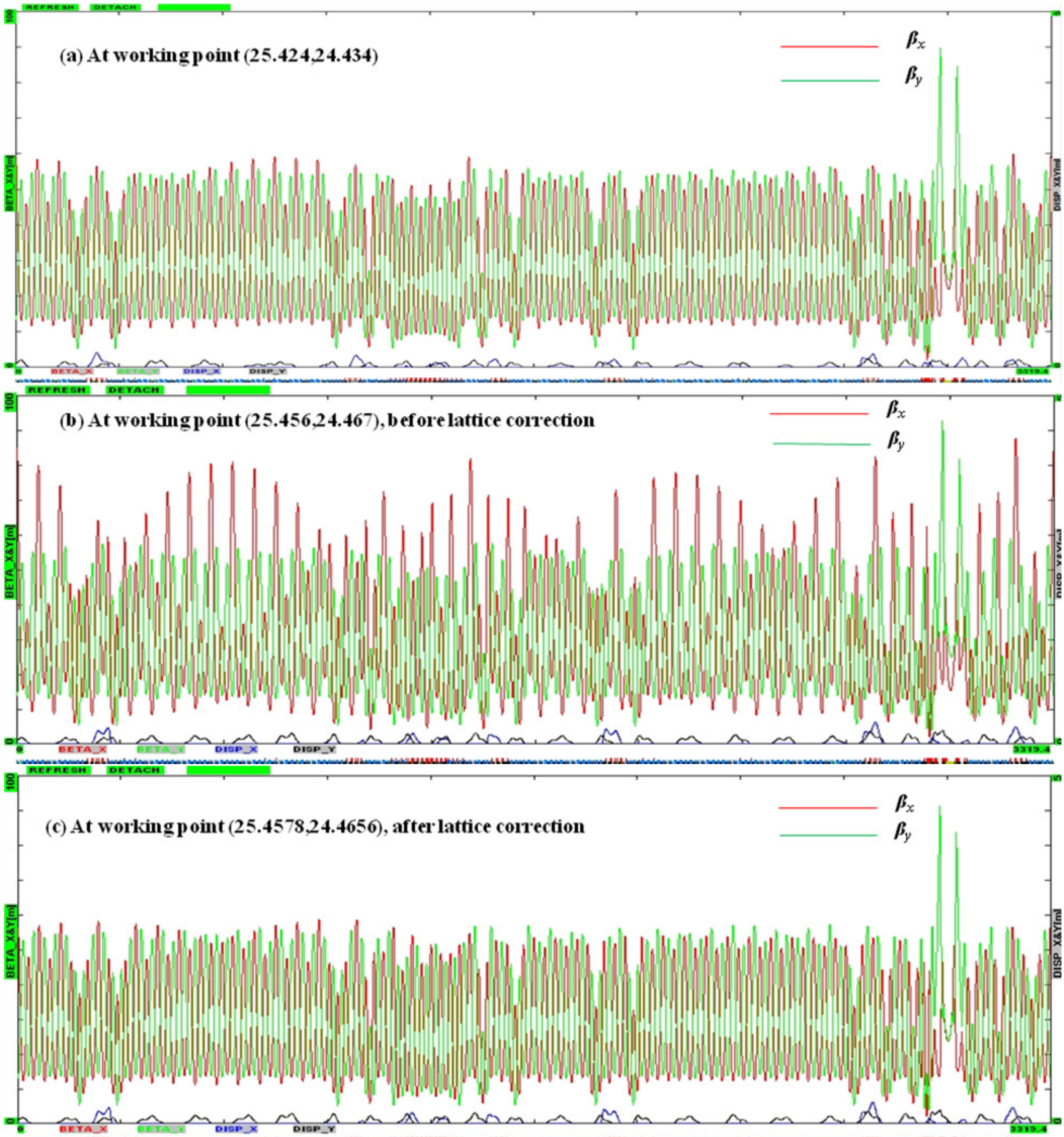

Figure 1: Beta- functions obtained from LOCO fittings using large number of differential orbit data

we found that the measured tune changes are very closed to the given tune changes, the difference is about 0.001.

Lattice measurement was again done by taking differential orbits data. Only 24 correctors were used this time due to limited time allowed, at the tunes set to (0.4578, 0.4656). We did the LOCO fittings and obtained the beta-functions from this measurement, shown in Fig. 1(c). We can see that the beta-waves are significantly reduced now in horizontal plane, compared to those in Fig. 1(b).

MEASUREMENT OF CURRENT LATTICE WITH NEW TROMBONE STRUCTURE

It was asked to explore the performance if the working point is moved to the region of 0.2-0.25 in tune diagram when the particles of the stored anti-protons in RR are increased to 600E10. The tune changes needed are ν_x =-0.2, ν_y=-0.2. However, maximum tune changes at the lower end can only be approximately ν_x =-0.06, ν_y=-0.18 with the limit of quadruple current up to 6.5 Amperes.

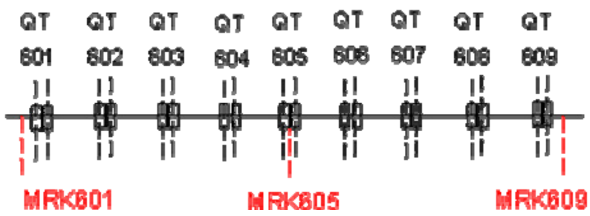

Figure 2: Phase trombone RR-60 Straight section

With the help of the upgraded program TROMBONE, we found that if the given tune changes are ν_x =-0.2, ν_y=-0.2, the current of 9 quadruple circuits would be :

I1,I2,…,I9 = (5.984, -9.308, 8.900, -8.762, 6.018, -8.007, 8.810, -9.913, 6.225)

If we install one more pair of trim quads at the existing location, the current of each circuit would be brought down to less than 5.0 Amperes. It would be the easiest way to extend trombone tuning range. The proposal was accepted, and it was implemented during 2007 Summer Shutdown. The new phase trombone section was shown in Fig. 3

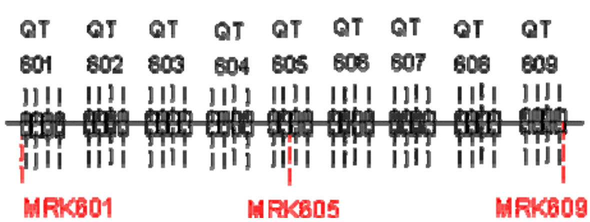

Figure 3: New Phase trombone RR-60 Straight section

We modified the test program in MATHEMATICA so that it accommodated the new trombone structure. The general equations with new trombone structure were obtained. Console application program TROMBONE was also modified for the new trombone structure, and the tune measurement showed that the difference between the given tune changes and the measured tune changes was within 10%.

Differential orbits of 48 correctors were taken at the tunes set to current working point (0.4593, 0.4657). We did the LOCO fittings, and beta-functions obtained are shown in Fig. 4. It makes sure that there is no beta-wave in the ring.

CONCLUSION

The Recycler lattice has been measured and corrected as needed. The trombone tuning range was extended to reach the lowest tune of 0.2 in both planes by installing one more pair of the trim quads. The console application program TROMBONE has been upgraded several times and it works well now in operation.

REFERENCES

[1] M. Xiao, et.al, "Linear Lattice Modeling of the Recycler ring at Fermilab". Proceedings of EPAC 2005, Edinburgh, Scotland. P2056-2058.

[2] Gerry Jackson, "The Fermilab Recycler Ring Technical Design Report"Fermilab-TM-1991, November 1996.

[3] M. Xiao, "Phase Trombone Program Migration for the Recycler Ring at Fermilab". Proceedings of 2005 PAC, Knoxville, Tennessee. P3135-3137.

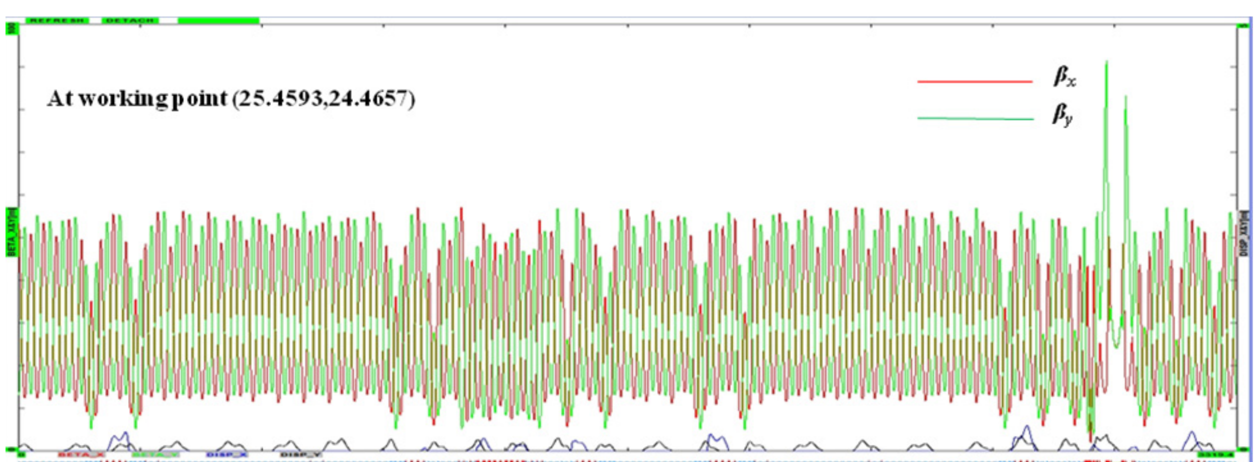

Figure 4: Beta-functions of current lattice obtained from LOCO fittings using large number of differential orbit data