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Long–term tracking for the LHC including ripple

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Abstract

Long–term simulations for the LHC lattice version 2 have been performed including tune modulation. As a first step tune ripple amplitudes and frequencies as measured in the SPS have been used. The influence of tune ripple has been studied for a good and very bad random distribution of magnetic errors.

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1 Introduction

It is known since some time [1] that tune ripple can further reduce the dynamic aperture when strong non–linearities are present. It may, however, be necessary to follow the particles over very long time scales to actually see the reduction of the dynamic aperture. An attempt has therefore been made to reach a sizeable fraction of the 10 minutes which particles will have to stay in the LHC at injection energy before the acceleration can start.

From the experience of present super–conducting hadron accelerators a rough estimate of the magnet errors can be derived. However, little is known about the level of tune modulation to be expected from the power supplies of the LHC. As a first guess the measured tune ripple of the SPS [2] has been used.

The simulations of the LHC lattice including tune modulations have been performed on the PaRC system [3]: a IBM SP1 clustering 8 IBM RISC stations R6000. Two seeds of random magnetic errors and several ripple depths were tested. For every case, 64 particles were tracked up to 3 million turns (about 5 minutes of real time) which takes 15 to 20 days of CPU–time each. For this purpose the tracking code SIXTRACK [4] has been adapted to the RISC stations to render optimal tracking speed [5]. Moreover we have set up the program to allow a prolongation of tracking runs from intermediate turn numbers to minimise the loss of data in case of a system crash. However, for this complete study no such system crash occurred.

Of course, half a month of CPU–time has to be considered the ultimate acceptable limit. Therefore only few, carefully chosen, cases can be treated in this way.

2 Results

The LHC lattice version 2 is used at injection energy with the newest available set of multi-polar errors [6]. For both seeds of random magnetic errors it has been made sure that only few values are outside and close to 3σ of the distribution (for the time being no cut in the distribution is applied in SIXTRACK). In both cases a non–linear detuning correction à la Giovannozzi [7] with sextupoles and decapoles has been performed. As usual round beams are tracked (equal horizontal and vertical emittances) and the full 6d phase space (transverse and longitudinal) is considered with a relative momentum deviation of 1.25×10^{-3}.

As a modulation spectrum seven ripple lines in the range from 50Hz to 1000Hz were taken from reference [2]. Their ripple depths (ΔQ) are ranging from about 5×10^{-6} to 5×10^{-5} with a total cumulated depth of roughly 10^{-4}.

Figure 1, 2 and 3 show the survival plots of a "good" seed denoted by 3,000,000. In these figures (and all others) only those particles are shown which have been lost before 3×10^6 turns (for reference one stable case is left at very low amplitude). In figure 1 the simulations are shown for the case with and without tune modulation. Up to 1×10^5 turns there is no indication of any difference. First signs of a lower dynamic aperture become apparent in the case with ripple beyond that turn number. This becomes clearer when the ripple depth is increased by a factor of 5 (figure 2) but also in that case a minimum of 1×10^5 turns is needed to see any effect of tune modulation. This larger tune ripple may be realistic because we have taken the SPS ripple as a starting point which, given the same quality of the power supplies, would be about a factor of 3 too low due to the difference of tunes of the 2 machines. The border of stability for the tracked 3 million turns shrinks from 8.2mm to 7.2mm when the strong ripple (5 times the SPS ripple) is used. That is a reduction of the dynamic aperture by 12%. Shown in the same graph are the borders of onset of chaotic motion which in the case of increased ripple depth is reduced by about 10% (6.3mm compared to 5.8mm). It is interesting to note that the border of chaotic motion is not altered when the ripple is increased by another factor of 2, the faster loss above 1×10^5 turns is, however, more pronounced in that case (figure 3). We expect stable particle motion below the chaotic border and indeed the entry at 2mm is completely stable over 3×10^6 turns.

In the next 2 figures (4 and 5) a very "bad" seed is shown denoted by 1,000,000. In this case the dynamic aperture is reduced by a factor of 1.5 compared to the "good" seed. Figure 4 shows again that there is no difference in loss times with or without ripple before 1×10^5 and here even above 1×10^5 turns the difference is not pronounced. Increasing the ripple depth by a factor 5 (figure 5), as in the other case, leads to faster particle loss beyond the 1×10^5 turn number and the stability border for 3 million turns is decreased from 5.9mm to 4.9mm, i.e. by 17%. The reduction of the border of chaotic motion is even more pronounced in this case: some 30% from 3.2mm to 2.3mm. As expected from these borders the entry at the lowest amplitude value (no ripple) does not show any sign of instability.

3 Conclusion

A reduction of the dynamic aperture of more than 10% has been observed when a tune ripple is considered which is 5 times the measured values of the SPS. The border of chaotic motion is reduced by at least 10% for both seeds and a faster loss can be observed beyond 1×10^5 turns.

For a more realistic evaluation of the effect of tune modulation a better estimate of the LHC tune modulation spectrum is needed. To this end studies are pursued to derive such a spectrum from LHC magnet measurements and calculations. Moreover the frightening small dynamic aperture for the "bad" seed needs to be better understood.

4 Acknowledgement

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References

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Survival Plot of LHC Version 2, Random Error Seed=3000000
1.00E+07
1.00E+06
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
Turn Number
No Ripple
Ripple
6
7
8
9
10
11
12
13
Horizontal Start Amplitude [mm] at beta=172m

Figure 1:

Survival Plot of LHC Version 2, Random Error Seed=3000000
20000 turns chaotic borders
1.00E+07
1.00E+06
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
Turn Number
0
2
4
6
8
10
12
14
Horizontal Start Amplitude [mm] at beta=172m
No Ripple
5*Ripple

Figure 2:

Survival Plot of LHC Version 2, Random Error Seed=3000000
20000 turns chaotic borders
1.00E+07
1.00E+06
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
Turn Number
0
2
4
6
8
10
12
14
Horizontal Start Amplitude [mm] at beta=172m
No Ripple
10*Ripple

Figure 3:

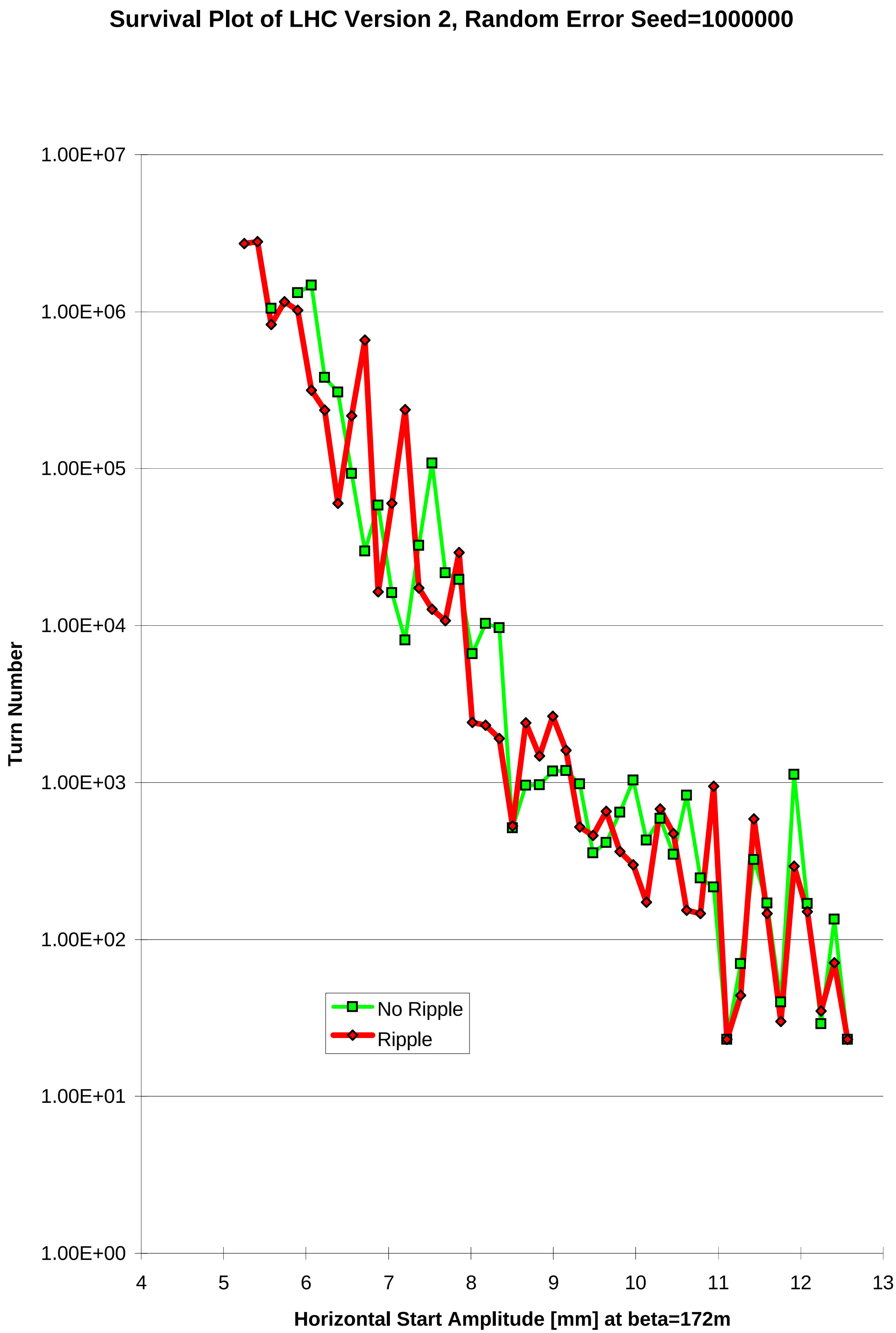
Survival Plot of LHC Version 2, Random Error Seed=1000000
Turn Number
1.00E+07
1.00E+06
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
4
5
6
7
8
9
10
11
12
13
Horizontal Start Amplitude [mm] at beta=172m
No Ripple
Ripple

Figure 4:

Survival Plot of LHC Version 2, Random Error Seed=1000000
20000 turns chaotic borders
1.00E+07
1.00E+06
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
Turn Number
0
2
4
6
8
10
12
14
Horizontal Start Amplitude [mm] at beta=172m
No Ripple
5*Ripple

Figure 5: