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NUMERICAL STUDY OF INTRINSIC RIPPLES IN J-PARC MAIN-RING MAGNETS

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Abstract

Numerical simulation results on intrinsic ripples in the J-PARC Main-ring synchrotron magnets are presented. Intrinsic ripples unavoidably arise in synchrotrons when the magnets are operated by acceleration pattern currents. The simulations are carried out with 3s and 1s of repetition cycles for the QFN magnet family, one of the typical large magnet families in the J-PARC MR. The simulated circuit is similar to the present QFN magnet system in operation with the 79Ω damping resistors. The obtained current deviation rates range in the orders of 1e-5 to 1e-3, depending on the simulated conditions. With the 1s repetition, the intrinsic ripple amplitudes increase by nearly one order compared to the 3s repetition case.

INTRODUCTION

In high power proton synchrotrons, stable beam accelerations with small losses are always in strong demand. In order to achieve this requirement, the ripples of the beam guiding fields are commonly needed to be suppressed to the order of 1e-6. Besides various possible ripple origins, recent studies revealed the existence of intrinsic ripples in the ramp pattern operations of the synchrotron magnets. It was first pointed out in a simplified magnet circuit [1], and more detailed ripple generation mechanisms will be presented in independent papers. In this article, in order to evaluate the intrinsic ripple magnitude in the realistic J-PARC MR operations, simulations are carried out based on the currently used magnet circuit, and the results are presented.

SIMULATIONS

The exemplified magnets are the QFN family in MR, which contains 48 identical magnet units. Figure 1 shows the simulated QFN magnet circuit. In order to simplify the simulations, the 48 magnet units are grouped into six, suffixed as 1 to 6, and each group contains 8 identical magnets, suffixed as "mag". All the magnet units are symmetrically divided into two parts, i.e. the N pole coils and the S pole coils, suffixed as A and B. In the present MR, all the magnets are connected by shielded cables, and their circuit parameters are derived from their estimated lengths, suffixed as "cab". Resistors are connected in parallel to all the magnets in order to speed up the damping of the ripples. In the simulations, all the parallel resistors are chosen as 79Ω, which is exactly the same as the resistance value in use. For each 8 magnets group in Fig. 1, the parallel resistance is 79 x 8 = 632Ω.

The assumed ramp pattern of the QFN magnet current is shown in Figure 2. The pattern is generally based on the initially designed acceleration cycle of J-PARC MR in the 30 GeV operations. The repetition rate is 3 seconds per cycle. When the repetition rate is increased by 3 times to 1s/cyc, all the parameters in the horizontal axis are assumed to shorten by one third.

The circuit simulation code used in this article is a common SPICE simulator, which is provided by Linear Technology Co., Ltd. with the simulation package name of LTSpice [2].

RESULTS

Simulated results with 3s repetition are shown in Figure 3. In the top graph, Fig. 3(a), one ramp cycle of the magnet current is displayed. The current deviations on the cables and on the magnets are plotted in Fig. 3(b) and (c), respectively. The magnet deviations 3(c) largely differ from the cable deviations 3(b). The difference is caused by the branched currents to the parallel damping resistors as are shown in Fig. 3(d). The damping resistor currents reach the order of hundred mA.

In Figure 4, the current deviation rates on the cables and the magnets are plotted with logarithmic scales. While the deviation rates on the cables in Fig. 4(b) are in the 1e-5 order at the beginning of the ramping, the rates on the magnets in 4(c) exceed 1e-3 due to the branched currents to the damping resistors. Increasing the parallel resistance values may decrease the branched currents, but it causes the longer damping of the current deviations. Since the damping resistor currents are mostly equal among the resistors as are seen in Fig. 3(d), regulating the ramp pattern output by the nearest magnet current may eliminate the influence by the damping resistor currents.

The repetition period of the ramp pattern is shortened to 1 second per cycle, and the simulated results are shown in Figure 5. The current deviation rates on the cables in Fig. 5(b) are nearly one order bigger compared to those in Fig. 4(b). In the single magnet case [1], the ripple amplitudes are found to be proportional to D/T_S where D is the current ramp rate and T_S is the parabola smoothing time. The comparison between Fig. 4(b) and 5(b) suggests the similar relation holds, not only for the single magnet case, but also for the multiple magnets circuit of QFN.

The resulting deviation rates on the cables are in the order of 1e-4 at the beginning of the current ramp. For the magnets, the rates exceeds 3e-3, due to the tripled voltage difference at the magnet inductance.

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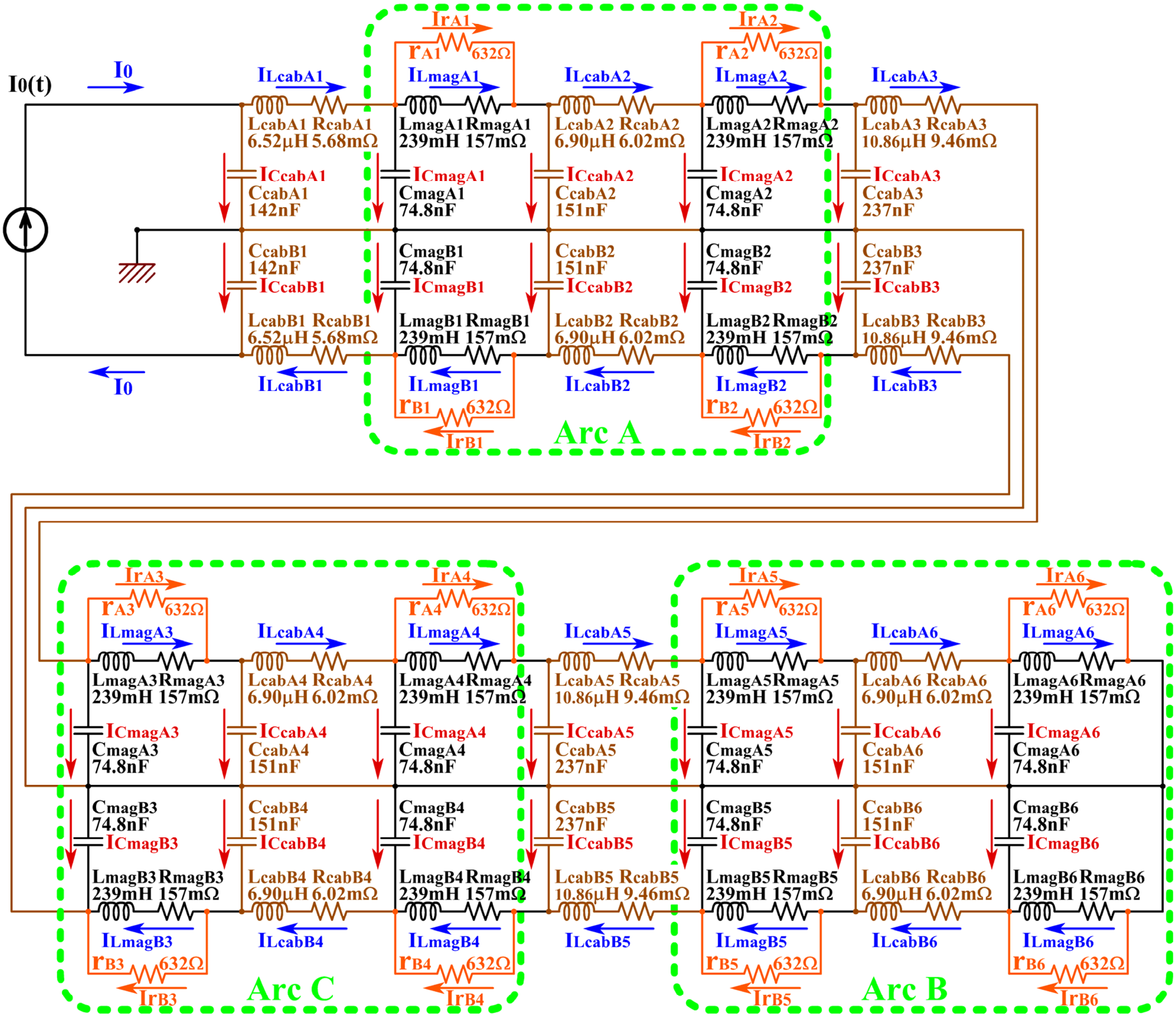

Figure 1: Simulated circuit of the J-PARC MR QFN magnets. The 48 magnets are grouped into 6, and each group has 8 magnet units. Cable parameters are derived from the estimated length. The damping resistors r_{An} and r_{Bn} are connected in parallel to the magnets. The resistance is 79Ω for each magnet, and for each 8 magnet group it becomes 632 Ω.

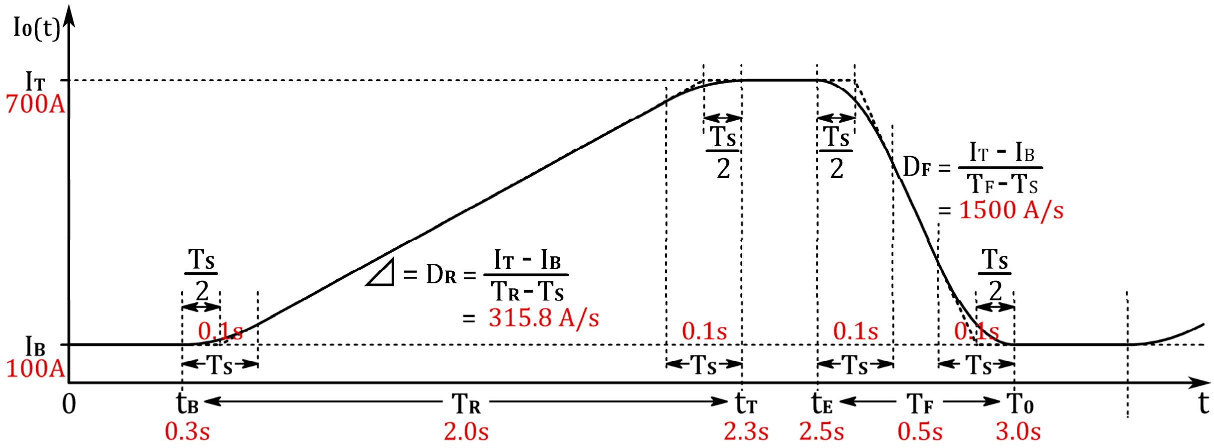

Figure 2: Simulated current ramp pattern for the QFN magnets. The pattern generally simulates the initially designed MR ramp pattern in the 30 GeV operations. The 1s repetition pattern is assumed to shrink horizontally by one third.

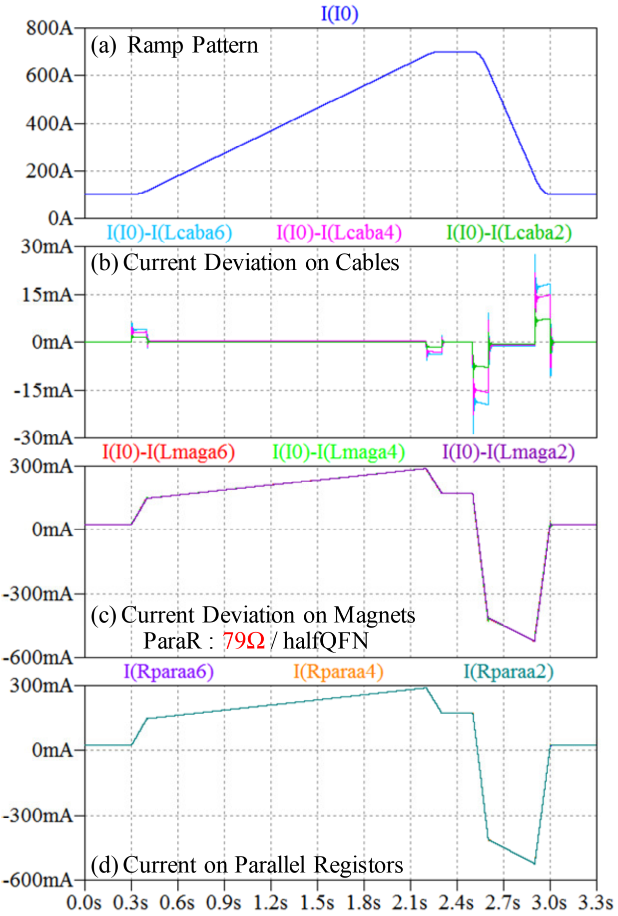

Figure 3: Simulations of the QFN magnet system in practical use with 79Ω parallel resistance.

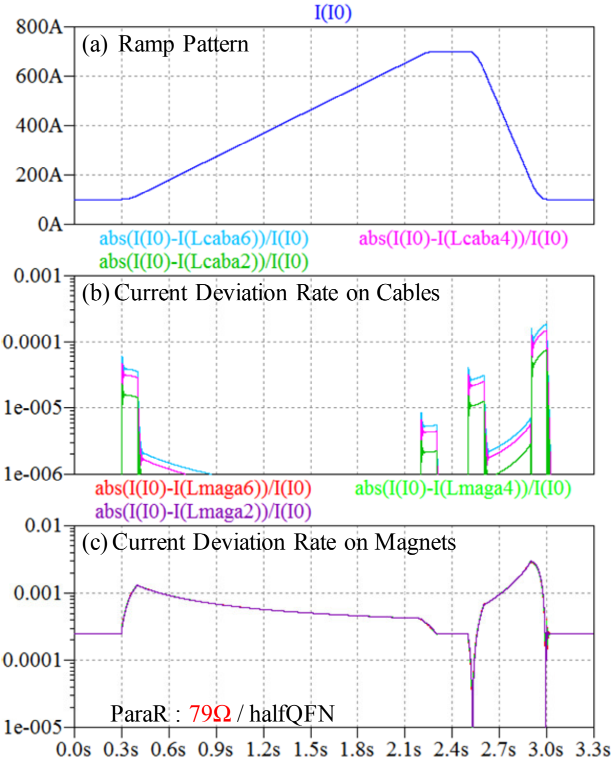

Figure 4: QFN magnet simulations with the logarithmic scales. The deviation rates exceed 1e-3 on the magnets.

CONCLUSION

The J-PARC MR QFN magnet is modelled, and the numerical simulations are performed by the SPICE simulation code. The ramp pattern is assumed to have 3s and 1s of repetition cycles. The intrinsic ripples, that occur whenever the ramp pattern currents are applied to the magnets, are obtained for the QFN magnet circuit in practical use. The deviation rates range in the orders of 1e-5 to 1e-3 depending on the cases. The current deviations on the magnets are largely increased by the damping resistor currents. The 3 times higher repetition rate results in nearly one order bigger deviation rates due to the intrinsic ripples. Beam simulations including these intrinsic ripple effects are being planned.

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[2] Linear Technology Co., Ltd. http://www.linear.com

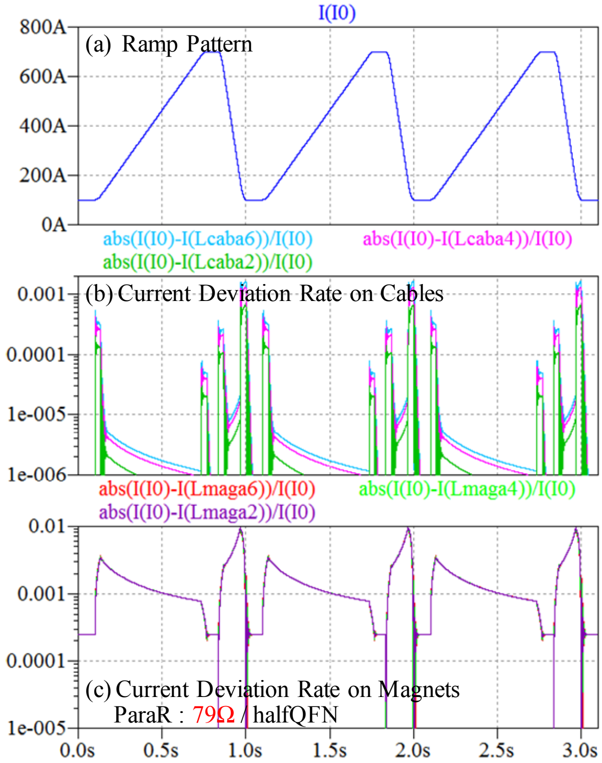

Figure 5: QFN magnet simulations with the 1s repetition cycle. The deviation rates are increased from the 3s case.