BATCH COMPRESSION FOR MULTI-MW J-PARC

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Abstract

Replacement of all J-PARC MR cavities has been completed in 2016 to increase the RF voltage. Nine sets of new high-gradient FT3L cavities will generate the required RF voltage for the 1.16 second cycle operation. Upgrade of magnet power supplies is planned and the cycle time becomes 1.3 seconds in FY2019 to achieve the beam power of 750 kW-1 MW.

For the further improvement of beam power, a new rapid-cycling booster is considered to increase the injection energy of the MR from 3 GeV to 6-8 GeV. By the reduction of the space charge effects, the injection time can be extended and a batch compression scheme becomes possible. It will increase the number of bunches from 8 to 11 or 13. A recent beam study of the 3 GeV RCS also suggests the capability of 6.6×10^{13} proton per bunch to accelerate. Combining these improvements, the beam power of 3 MW will be manageable.

INTRODUCTIONS

Between 2014 and 2016, all 9 cavities in a long straight section, Insertion C, of the MR were replaced with new FT3L cavities to achieve the beam power of 750 kW as shown in Fig. 1 [1,2]. The cycle time of the J-PARC will be 1.3 seconds in 2019 from 2.48 seconds. The upgrades of the magnet power supplies and RF systems are the key issues for high repetition. Three new power supply buildings are under construction to store magnet power supplies.

For the upgrade of RF system, the development of large size FT3L magnetic alloy cores has been started in 2010 [1]. The development results of the cavities are reported in [2]. After the cavity replacements, two of nine cavities are modified for the second harmonic RF systems to reduce the space charge effects during the injection. The available number of protons in the J-PARC MR becomes 2.4×10^{14} protons by reducing and controlling the beam loss. However, the cavity performance is limited by the anode power supply [1,3] under the heavy beam loading. To manage such a beam loading, the 5 cell cavity was modified to 4-cell type. It is planned to reinforce the anode power supplies and to prepare dedicated 2nd harmonic RF systems in another long straight section, Insertion A, for one MW beam operation.

MULTI-MW SCENARIO AFTER HIGH REPETITION

A recent beam study suggests that the beam loss of the J-PARC MR is dominated by the space charge effects during the injection [4]. It is also reported that the available beam

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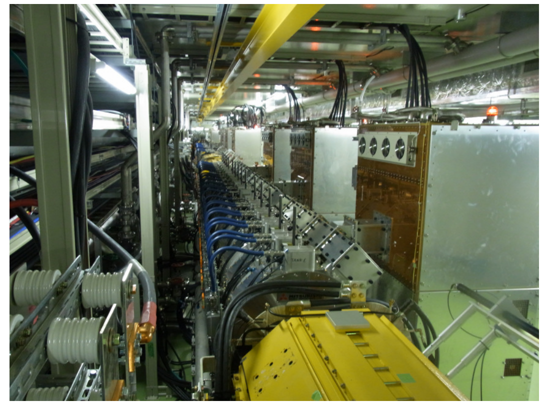

Figure 1: New cavities in the J-PARC MR.

power of the J-PARC RCS will be more than 1.6 MW after upgrading the RF system [5,6]. A new booster synchrotron is proposed to increase the beam intensity [7]. Although the 6-8 GeV booster will reduce the space charge effects significantly, the maximum power of the MR is limited up to 2.2 MW if the ordinary injection scheme is adopted. As the space charge becomes small, a bunch manipulation will be a technique to inject more bunches to the MR. In this paper, a batch compression scenario is presented to achieve 3 MW beam power.

Batch Compression

A batch compression is a technique to change the harmonic number of RF [8] and used in CERN PS. At the injection to the synchrotron, number of beam bunch is lim-

Table 1: High Repetition Scenario of J-PARC MR

	Present	2019	goal
Cycle Time	2.48 s	1.32 s	1.16 s
Acceleration	1.4 s	0.7 s	0.57 s
Protons/cycle	2.4×10^{14}	2.1×10^{14}	3.3×10^{14}
Beam Power	480 kW	750 kW	1.38 MW
RF Voltage			
Acceleration	300 kV	448 kV	540 kV
2nd Harmonics	110 kV	110 kV	110 kV
ϕ_s	20°	30°	32°
RF Cavities			
Acceleration	6-7	8-9	9
Location	Ins. C	Ins. C	Ins. C
2nd Harmonic	2	2	2
Location	Ins. C	Ins. A	Ins. A

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ited by bunch width and rise and fall times of injection kicker magnet. One of the advantages of the batch compression is that it does not require a difficult R&D for injection instruments to inject more bunches in a limited time duration [9]. Figure 2 shows a simple Visual Basic simulation including the injection process using the voltage pattern in Fig. 3. For the first 3 batches, K1-K3, 2 bunches are injected. After the 7th bunch is injected at K4, the batch compression starts from H=9 to H=13. When the harmonic number becomes 11, the 8th bunch is injected at K5. After the compression to H=13, 3 more bunches are injected at K6-K8. In this scheme, 11 bunches are injected in 8 batches (RCS cycles) as shown in Table 2.

The batch compression process is also studied precisely using a code, BLonD [10]. Figures 4 show the batch compression process in case of 8 batch and 10 batch compressions. Figure 5 show the combined voltage of two harmonic RF and bunch distributions during the batch compression from H=9 to H=10 which is the most important period to avoid the emittance growth and beam loss. Figures 5-(b) and -(c) show that the combined RF voltage is deformed although the RF voltage around each bunch is high enough to capture it. Figures 5 clearly show the space to inject the next bunches is going to be prepared by the batch compression.

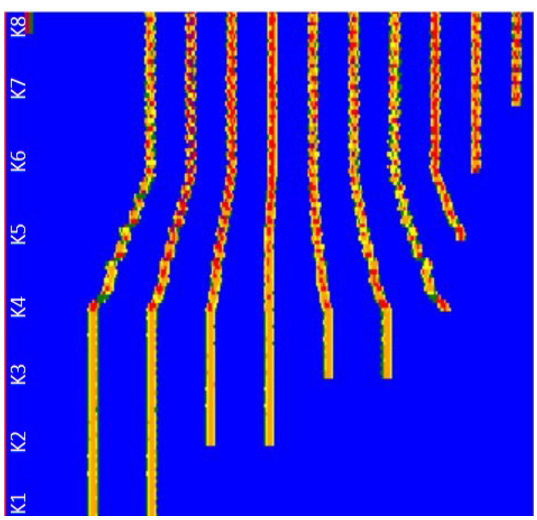

Figure 2: A contour plot to show a batch compression scenario to inject 8 batches and 11 bunches from the 6 GeV booster.

Injection and Extraction

The rise times of the present injection and extraction kicker magnet in the J-PARC MR is about 200 ns and 1.0 μs, respectively. When the harmonic number of the MR becomes 13, same kicker magnets can be used because the injected beam bunch from the 6 GeV booster has a narrow bunch width of about 100 ns. More kicker magnets are needed to inject the higher energy beam. For the extraction, two empty buckets are needed to use the same kicker magnets.

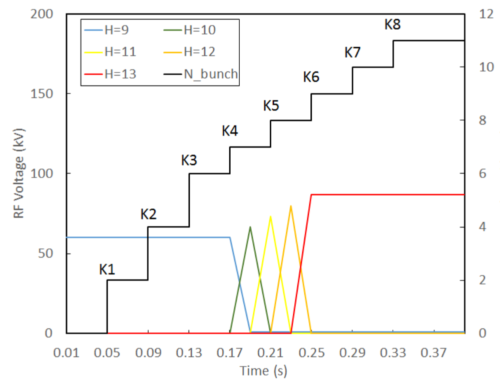

Figure 3: RF voltage pattern and number of bunches (black line) for a batch compression from H=9 to H=13. RF voltage increases according to the higher harmonics to keep the bucket size constant.

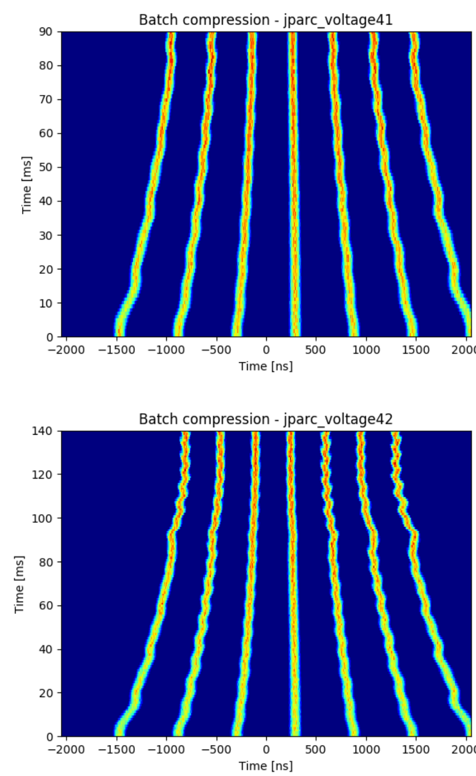

Figure 4: Batch compression simulations using a code, BLonD [10]. Top and bottom figures show the compressions from H=9 to H=13 and from H=9 to H=15, respectively.

3 MW Scenario

Table 2 shows two scenarios to achieve the beam power of 3 MW using the new 6 GeV booster. Assuming the beam power of the present RCS will be 1.6 MW, a batch compression from H=9 to H=15 will capture 13 bunches and 3 MW beam will be realized. The upgrade of the RCS beam power needs the replacements of the RF cavities to the FT3L type ones and reinforcement of RF power supplies [6]. When the

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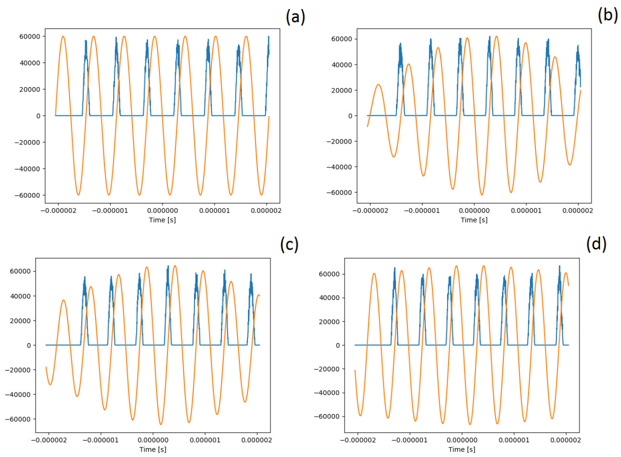

Figure 5: From (a) to (d), combined RF voltages (orange lines) and bunch shapes (blue lines) are shown for every 6.6 ms during the batch compression from H=9 to H=10.

Table 2: Batch Compression Scenario of J-PARC MR

Compression	**No**	**Yes**	
No. of Batches	**4**	**10**	**8**
RCS beam	1.6 MW	1.6 MW	2 MW
Cycle Time	1.16 s	1.4 s	1.32 s
Protons/bunch	6.6×10^{13}	6.6×10^{13}	8.3×10^{13}
No. of Bunches	8	13	11
H*	9	9-15	9-13
RF period	599 ns	359 ns	415 ns
Protons/cycle	5.3×10^{14}	8.7×10^{14}	9.2×10^{14}
Beam Power	2.2 MW	3.0 MW	3.3 MW

* H : harmonic number of RF.

beam power of the RCS becomes 2 MW equivalent, a batch compression from H=9 to H=13 will be enough to achieve 3 MW beam although the injection beam loss of the RCS should be reduced by improving the injection scheme.

Technical Requirements

To realize the batch compression in the J-PARC MR, the following RF items will be needed after the construction of the new booster synchrotron and reinforcements of injection line and instruments:

- RF System for the compression is needed. Ferrite loaded cavity is the first candidate to manipulate the beam. A wideband (Q=2-3) RF system to cover H=9 to H=13 is another candidate to handle very heavy beam loading. In case of ferrite cavity solution, four RF cavities will be needed for two harmonics as the typical available RF voltage of the cavity is about 40 kV. A heavy beam loading will be a problem to solve although the ferrite cavities are used in CERN PS [8]. In case of a wideband cavity solution, two RCS-type cavities are needed for two harmonics if 5-cell cavity can be used. As the wideband cavities will be affected by several harmonic frequency, beam loading compensation on multi-harmonics will be needed.
- Reinforcements of RF power supplies and amplifiers are needed to handle 3 times higher beam loadings. It is considered to increase the number of high power tetrode tubes and two sets of the present anode power supplies will be used for an amplifier. More anode power supplies will be needed to handle 3 MW beam.
- A longitudinal coupled bunch instability has been observed at the high intensity operation of the MR and the cure will be more important at higher intensity. A possible source of the impedance is the cavity impedance. After installing the new booster, the frequency sweep for the acceleration will be 0.5%. The bandwith of the cavities should be narrower to reduce the impedance at the source frequency. The bandwidth of the cavities are adjustable by changing the cut core gap [1].
- The second harmonic cavities in the Ins. A will be less important because of less space charge effects at 6 GeV. These cavities can be modified to the acceleration ones as back-up systems and it is helpful to maintain the stable operation.

CONCLUSIONS

A batch compression scenario is presented to achieve the beam power of 3 MW using a new 6 GeV booster.

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