Report from the14th Meeting of the Accelerator Technical Advisory Committee for the Japan Proton Accelerator Research Complex (J-PARC)

February 5 – 7, 2015
J-PARC Center
Tokai, Japan

Introduction

The Accelerator Technical Advisory Committee (ATAC) for the J-PARC Project held its fourteenth meeting February 5 – 7, 2015, at the J-PARC Center in Tokai, Japan.

The ATAC members are: Alberto Facco (INFN), Roland Garoby (ESS), Simone Gilardoni (CERN), Alan Letchford (STFC), Subrata Nath (LANL), Akira Noda (NIRS), Michael Plum (ORNL), Thomas Roser (BNL, Chair), Jie Wei (MSU), Robert Zwaska (FNAL). All ATAC members attended to meeting.

The ATAC thanks the J-PARC management and staff for their hospitality during this meeting, and all the presenters for their excellent and comprehensive talks. The Committee also greatly appreciates that the J-PARC team has specifically addressed all recommendations from the previous report.

The Committee is very impressed by the tremendous amount of work accomplished by the J-PARC team since the last meeting. After installation of the 400 MeV linac energy upgrade the previous year, a new ion source and a new RFQ was installed during the summer of 2014 and successfully commissioned to the goal intensity of 50 mA. Using the higher beam intensity the RCS design performance of 1 MW equivalent of beam power onto the MLF target was then demonstrated. The J-PARC team is to be congratulated for this achievement.

The Committee notes that in a very short time J-PARC has become a world leading neutron spallation source and MuSR facility with a large user community and has already achieved a break-through fundamental research result with the discovery of the electron-neutrino appearance from the T2K muon-neutrino beam. The hadron beam facility is poised to start a number of world-leading high precision particle physics experiments. This success of facility operations was achieved despite interruptions by the earthquake in 2011, a radiation release incident in 2013 and, most recently, a small equipment fire on January 16, 2015. In every case the J-PARC team responded quickly and proactively with the goal to bring safe facility operation back as soon as possible.

Beam power projections

RCS for MLF:

- Substantial progress has been made in demonstrating RCS capabilities, 500-600 kW is expected in the next few months of JFY2015, 700-1000 kW by the end of JFY2015.
  - Recent operation has been limited to 300 kW until the equipment fire in the MLF beamline. Higher intensities will be immediately available upon restart of the accelerator complex.
  - 1 MW operation requires modification of the RF anode power supplies this summer.
  - The 1 MW operation has been enabled by the linac upgrade to 400 MeV and the front-end upgrade to 50 mA.

- Studies were performed to demonstrate the capability of the RCS to operate at powers in excess of 1 MW. The study results are very promising and suggest producing 1 MW is feasible, even without full amelioration of the RF issues.
  - The study produced a beam intensity of 8.41×10^{13} protons, an intensity equivalent to 1.01 MW operation.
  - The equivalent beam loss was 300 W, the vast majority of which was from foil interactions and was directed to the collimator. This level of loss is acceptable for full power operation.
  - 40 - 50 W of the loss was in the arcs due to inadequate RF voltage and harmonics. This loss will be reduced by RF anodes supply improvement, but is not necessarily an impediment to operation. A short-period, sustained run at 1 MW appears to be possible now, and would be a useful tool to identify other near-term issues.
  - No extrapolation to higher beam intensity is necessary. The RCS is poised to reach its design intensity.

MR with fast extraction for neutrinos:

- Beam intensity is predicted to increase to 300 kW in the near future, and then increase to 300-350 kW by the end of JFY2015 until power supply upgrades are complete in several years.
  - Recent delivery to T2K has been 265 kW.
  - The RCS has demonstrated production of the beam intensity needed (2.09×10^{13} ppb) for 300 kW operations in the present configuration, and 750 kW operations with the upgraded power supply.
  - Studies in the MR have demonstrated 310 kW operations. Losses increased substantially in these studies (approximately three times), but are within acceptable limits
  - 750 kW is dependent upon successful MR RF improvements, and the MR magnet power supplies.

- J-PARC has adopted a plan to reduce the cycle time to 1.0-1.3 sec as its primary path to achieving 750 kW in the MR. As a result, the MR magnet power supply needs to be upgraded and the RF voltage needs to be increased.
    - Limitations in funding have delayed the power supply replacement, such that completion of the power supply upgrade is now expected for the end of JFY2018 (March 30, 2019). Without other improvements, it is only at that time that the fast extraction beam power will rise above 300-350 kW. Other options for improvement could be explored.

MR with slow extraction to the Hadron Facility:

- Beam is predicted at 20-50 kW in 2015, 100 kW by JFY17
    - Repairs to the Hadron Facility are mostly complete. Operations should be able to restart in the near future.
    - Beam of 24 kW was available before the incident at the Hadron Facility, and studies for 30 kW had been accomplished. No further studies for higher intensity have been possible in the intervening period.
    - Slow extraction at 24 GeV may provide advantages for operations, while having negligible impact on beam power and science production for the experiments. This option should be explored with users in the near future to establish operation plans.

- Slow extraction goals continue to appear challenging to achieve in the future. Intensity studies will be needed when restarting and should be accompanied by a reevaluation of long-term potential.

- The Committee continues to consider the SX performance goals to be placeholders until beam is again established and operational limitations can be re-examined.

MR with slow extraction to COMET

- Studies have started for the production of slow-extracted beam for the COMET muon-to-electron conversion experiment. This beam differs from previous slow-extracted beams.
    - The beam energy is 8 GeV to suppress antiproton production, and therefore is larger at extraction.
    - The beam is bunched into 4 buckets, interleaved with empty buckets that must have a very high level of extinction (better than 1e-9).

- Beam is expected to be available for the experiment in two phases.
    - Phase I has beam power of 3.2 kW in 2017.
    - Phase II has beam power of 56 kW in 2019-2020.

- An initial set of studies identified several approaches to achieving the Phase I goals.
    - Improvements in emittance, extraction efficiency, and transport acceptance are possible to reach the Phase I goals.

    - Changes in the kicker pattern showed large improvement in extinction to ~ 1e-11 – more than sufficient for that stage of the experiment.
    - Further studies are planned to verify these approaches.

- An initial set of parameters for Phase II operation was presented to the committee. These parameters rely on the power supply upgrades and several additional upgrades to the MR. A much higher beam intensity is also required. A campaign of beam studies will be required to substantiate these parameters.

The cost of electricity for J-PARC has more than doubled since the 2011 earthquake and facility operations and facility upgrades are being affected by this substantial added cost. Since it is not expected that the cost of electricity will come down again and for general reasons of conserving energy, energy efficient operation needs to be a priority for J-PARC. There might be a number of opportunities to reduce the energy consumption of the facility with targeted investments that could reduce the operating costs substantially.

R1: Explore targeted investments that reduce the energy consumption and operating costs of J-PARC.

Ion Source and RFQ

Status and main achievements

The current has been successfully upgraded with new Ion Source and RFQIII. The new source with internal antenna, rod-filter magnets, plasma electrodes and new ceramic vacuum chamber is in operation. A beam current of up to 65 mA was demonstrated with the new source.

The ion source and the RFQ were continuously operated in the Test Stand for about one month assuring its performance. The ion source and the RFQ were then moved to the tunnel in the summer of 2014 and have been successfully operated since the end of Sept 2014 delivering 50 mA beam. Preparation is underway for a stand-alone test stand for the ion source. This is in addition to a separate test stand comprised of an ion source and RFQ combined system.

Comments

- The RFQ output emittance is larger than the specification but appears to cause no issues in the rest of the linac.
- An ion source antenna failed after 654 hours of operation due to cracking of the ceramic insulator. This is consistent with similar ion source systems. Premature failure of the antenna would adversely affect source lifetime, and thus impact beam-time availability. Understanding the failure mechanism and improvements of the antenna coil would be beneficial.
- The RFQ trip rate is going down with time but is still about 10 trips per day.
- The RFQ transmission is in good agreement with simulations but is rather low at 80%.

Linac Status

Main achievements
In October 2014, after installation of the new front end system and the upgraded chopper during the planned summer shutdown, the linac achieved the goal of accelerating 50 mA beam to 400 MeV, according to the plans, after less than three weeks of commissioning.

Comments and recommendations
This achievement was accompanied by several, but not yet critical problems in the linac:

Significant linac downtime before and after the upgrade was caused by the failure of three vacuum flanges clamps made of aluminum. All 258+50 aluminum clamps were preventatively replaced with new, stainless steel clamps. The reason for the failures needs to be understood since it could also affect the new clamps.

Multipacting in SDTL05 and SDTL06 varied with time and its band reached for long periods the beam operation power level. RF conditioning did not succeed. After applying, without success, the standard techniques for MP reduction, it was found that cavity detuning can lower the upper MP boundary to below the operation field at the expenses of an increased RF power dissipation. This is expected to be a short term mitigation for this problem, which could be maintained for the next two years. The tuner geometry and position is suspected as the main source of MP, but this is still under investigation. The coupler seems to be involved in the MP too.

The proposed solutions are: 1) moving permanently the variable tuner into a low MP position and recovering the frequency with the fixed tuner; 2) applying surface treatment such as TiN coating for MP reduction to tuners; 3) replacing the present rotatable coupler with a retractable one of the type used in higher beta modules without MP.

Even larger detuning could be explored for a possible widening of the MP band, since the rf power limit has not been reached yet.

The detuning solution can be only a temporary one because the upper MP boundary in SDTL05 and 06 have shown to vary with time. A more durable solution is needed.

R2: Develop a clear mitigation plan for the worsening Multipacting problem of SDTL05B. Pursue, with high priority, improvements of the existing cavity and/or manufacturing of a new cavity.

The replacement of the MEBT1 chopper with a new one with larger aperture has succeeded in reducing beam losses at 50 mA, according to the plans. After removal from the beam line the used beam scraper has shown craters 0.3 mm deep after 2 months of operation at 30 mA and 25 Hz. This was considered acceptable by the accelerator team. To cope with 50 mA, reducing the incident angle on the scraper from 45 degrees to 23 degrees with respect of the beam axis is expected to nearly halve the power deposition density and double the scraper lifetime. Another factor of two will be obtained by chopping the beam by deflecting it on two scrapers located on opposite sides. This system was tested for a relatively short time with the beam, showing its feasibility. However the temperature of the scrapers exceeded the saturation point of the measurement system and no measurement of the steady state temperature could be obtained.

The scrapers operation at 50 mA in steady state has not yet been demonstrated with sufficient reliability.

Halving the angle might not halve the power density because of the different penetration of the beam into the scraper at 3 MeV. Measurements of the scraper temperature during operation is needed to understand scraper erosion and operation lifetime

R3: Test the new chopper-scraper system in the steady state with an accurate temperature measurement of the scrapers to demonstrate reliable operation.

The Bunch Shape Monitor (BSM), which had to be removed for vacuum problems before the summer shutdown, was reinstalled after baking, together with three additional TMP units. This improved the vacuum and its degradation during BSM operation is now acceptable (from 7E-7 to 9E-7 mbar). The unit is going to be re-fabricated for operation in good vacuum conditions without additional TMP to save space.

The linac sections were found displaced by less 0.3 mm during the 2014 summer shutdown, but all within specified tolerances. Re-alignment will be done during the next maintenance periods if further displacements exceeding specifications are observed.

Linac beam studies

Main achievements

In addition to the 50 mA achievement, the beam emittance, beam profile and beam losses were measured in different parts of the linac. This gave important information on the actual beam transport problems and possible solutions. Some important discrepancies between calculated and measured values were found in the MEBT1, wherein transverse emittance growth partially explains increase in relative beam losses at 50 mA compared to the 30 mA case.

The beam emittance was measured at the RFQ exit and found to be close to specifications at 50 mA.

The MEBT1 lattice transmission was found to be inconsistent with simulation. Transverse Twiss parameters at the RFQ exit were calculated from results of Q gradient measurements at the MEBT1.

Longitudinal parameters were reconstructed after beam transmission measurements through the DTL. The beam injected in the SDTL could be matched properly at 30 mA, as before the upgrade, while this was not possible at 50 mA where the beam showed significant halo.

Longitudinal emittance measurement in MEBT2 showed values 70% larger than the design.

The beam profile at the end of ACS section shows the presence of beam halo at 50 mA.

At 50 mA a transverse emittance increase of 50% is observed at the MEBT1 in both planes, confirming a still problematic lattice setting in that section. Only small emittance increase is observed at 30 mA.

Significant beam loss is observed at the L3BT magnet at 50 mA, but not at 30 mA. This loss disappeared after chopping, and was interpreted as due to longitudinal halo caused by transient in the ion source/RFQ pulsed operation. Chopping removes the problem completely.

Residual radiation at the ACS is higher in specific position where the aperture is reduced. Replacement of components with other ones with larger aperture is planned for the next shutdown. This is expected to eliminate the problem.

The beam suppression by the chopper was measured and found well within specifications. However, ringing between the two chopper cavities powered by the same rf amplifier caused beam trajectory distortion and increased losses in the DTL. This is suspected also to be the main cause of transverse halo at the RCS injection. Chopper ringing will be addressed by powering the two cavities independently. This is expected to reasonably eliminate ringing.

Comments

The main causes of emittance increase, halo formation, beam losses and residual radiation seem to have been properly pointed out. Promising solutions have been proposed for most of them with the exception of the MEBT1 lattice, which seems to be still not completely understood.

The effort of understanding the MEBT1 lattice should be continued to bring the 50mA beam parameters along the linac within the specified values.

3 GeV RCS status and beam studies

Status and main achievements

- A major milestone of accelerating a 1 MW equivalent beam in the RCS was achieved in December 2014.
- Routine stable operation is at 300 kW.
- Below ~900 kW beam loss increases linearly with beam power. Loss is primarily at injection due to foil scattering.
- To achieve the 1 MW equivalent beam required retuning the RF cavities (1.7 -> 2.1 MHz), increasing the over-current level of the anode PSUs (110 -> 125 A) and disabling higher harmonic beam compensation to prevent RF system trips.
- The compromised RF system operation at the 1 MW level resulted in additional longitudinal beam loss in the high dispersion area and on the collimators.
- Major sources of downtime: failure of an oil cooling pump in the bending magnet choke transformer and diode failure in the bump magnet power supply.

- Modifications to the bump magnet power supply have resulted in a flat top of +/- 0.25% now being achievable.
- Addition of extra turbo molecular pumps and new bellows has improved the vacuum system in the RF section.
- Replacement of the MA cores in cavity #6 means all cavities except #11 now have new type cores.
- Improved radiation shielding and diagnostics have been installed in the 100-degree dump line.
- A larger than expected injected beam emittance with significant halo at 50 mA has been compensated for by a modified transverse painting scheme.
- High activation areas have been identified at the foil chamber (7 mSv/hr) and the dump line windows (8 mSv/hr).

Comments and recommendations

- The team is to be congratulated on demonstrating 1 MW equivalent operation.
- According to the "delayed power scenario" the RCS should be operating at >600 kW but routine operation is only at 300 kW. However the goal of >600 kW in JFY2015 seems readily achievable.
- 1 MW operation for short durations seems achievable with no further modifications. However, to provide operating margin and to reduce beam loss it is preferable to improve the anode current available to the RF system. Without these modifications the RCS seems capable of sustained operation at 700 kW or higher.
- Only one instability seems to be present – the extraction kicker impedance instability. It appears to be well controlled by controlling the betatron tune and the chromaticity.
- The Committee supports the plan to correct the beta beating to further increase the emittance of the beam in the ring, and thereby reduce the beam loss due to foil scattering.
- The extracted emittance at 1 MW is permissible for MLF but mitigation is required for MR. The beam parameters for 750 kW MR operations with 1.3 s repetition period have been shown to satisfy the 3-50BT collimator beam loss criterion.
- Foil scattering loss can be reduced by 1/3 by increasing the painting area. However to achieve this the injected beam emittance will need to be reduced or the halo removed by the L-3BT scraper.

R4: Consider running with 1 MW of beam power onto the MLF target for a short duration just before going into the summer outage to test operational issues of running at design beam power.

<u>Main Ring, including MR PS upgrade</u>

Findings and comments.

A new beam profile monitor using optical transition radiation detectors were installed in the RCS-to-MR transfer line to characterize the beam delivered from the RCS. This profile monitor is particularly useful for beam halo measurements.

MR operation was tested up to 311 kW with beam losses of about 1 kW, mostly at the beginning of acceleration.

A number of efforts were oriented toward operation above 300 kW: β modulation correction with a quadrupole trim coil, 3rd order resonance correction with sextupole trim coil, a 2nd harmonic RF, and exploring a new operating point (21.4, 21.4).

The new operating point is close to the coupling resonance and there is a 3rd order structure resonance nearby. The new operating point works well for high intensity beam at injection. The betatron tune space in the MR should be further explored for working points with lower losses.

The design of the new MR PS is well advanced and tests with a 1/3 unit were very successful. The choice of the technology was approved by an external review committee. However, the JFY15 budget for the new MR PS was not approved. This will delay the new power supply by one year and consequently delay 750 kW operation to 2019 or later.

The timely completion of the new MR PS to allow for 1 Hz operation remains the highest priority upgrade for the MR and is critical to reach the design beam power of 750 kW.

A high harmonic "dilution" rf system (~ 100 MHz) can be very effective in improving the bunch shape and to allow for controlled emittance blow-up. This will likely reduce the instabilities observed at low energy and allow for high beam intensity. In addition, such a high frequency rf system can be used to improve the spill structure of the slow extracted beam.

R5: Consider implementing a high harmonic rf system in the MR allowing for controlled emittance blow-up and instability suppression at low energy.

The beam from the RCS, with the 400 MeV linac energy, has a low enough emittance to be transported to the MR with low losses. Alternative schemes to increase the MR intensity could be investigated such as operating the RCS with harmonic number one and accumulating 8 RCS cycles in the MR. To be successful such schemes will likely also require the implementation of the 2^{nd} harmonic cavity or the "dilution" cavity, an optimized tune working point and effective transverse damping systems.

R6: Explore additional possibilities to increase the MR beam power prior to the completion of the MR power supply upgrade.

<u>MR injection and fast extraction upgrade</u>

Primary achievements:

Routine production beam power of the MR has increased to 265 kW since the 2014 ATAC meeting. Measurements and testing at the higher power of 310 kW shows that the beam loss is disproportionally higher: about a 300% increase in beam loss for a 17% increase in beam power. To operate at beam powers above 265 kW requires improvements to the injection, extraction and transverse damper systems.

The injection kicker system is being improved by shortening the rise time and mitigating the oscillations in the tail. The shortened rise time will give a longer flat top and thus allow longer beam pulses to be injected. However, the circuit to improve the rise time has the consequence of worsening the tail oscillations. A compensation kicker is planned to be installed in April 2015.

Improvements are also planned for the first injection septum. The existing septum magnet suffers from a crack or separation at the end plate welding. Both a new septum magnet and a new power supply are planned to be installed during the summer of 2015.

The existing FX kicker power supply suffers from resistor damage. Similar issues were observed and then solved with the injection kicker, and this gives confidence that a similar remedy will work for the extraction kicker. This is planned to be installed during the summer of 2015.

The low field extraction septum is being changed to an eddy current type septum. The existing magnet suffers from vibration and decline of the ceramic spray coating. The new magnet and power supply have been built and tested. Installation is planned for the summer of 2016.

The high field extraction septum is also being replaced. The design is in progress, and installation is planned for summer 2017.

The risk associated with the new power supplies and magnets appears to be low. The issues with the existing power supplies and magnets appear to be well understood and the new designs take advantage of the lessons learned.

MR slow extraction

Findings and comments

The repair of the low field magnetic septum for slow extraction is progressing well. The source of the septum failure was identified. The soft soldering between the cooling pipe and the septum blade was not providing sufficient mechanical stability and thermal contact, leading to a significant deformation of the blade. The brazing of the cooling pipe on the septum blade should solve the issue, and the septum was ready for installation in September 2014.

All vacuum chambers around the slow extraction area were replaced with chambers made of titanium to minimize activation from the large losses during slow extraction. However, a new Ti bellows near a collimator developed a vacuum leak and all the new Ti bellows were removed and the original equipment was reinstalled. The reason of the failure is not understood.

Whereas the failure of a single bellows might indicate a manufacture issue, also the local machine alignment should be investigated to determine if unusual mechanical stresses are applied in the region that might enhance the fatigue of the welded parts.

The Electro-Static Septum (ESS) preparation is progressing, even if the design voltage could not be achieved yet. 114.5 kV could be reached instead of the nominal 120 kV with a 30 mm gap. The reason was identified as related to eddy currents appearing around the cathode electrodes that should be reduced thanks to an adequate coating. Then, after a period of conditioning, the gap size will be reduced to 25 mm.

The SX consumes 27 MW whereas the FX consumes only 24 MW of electric power. Reducing the SX energy from 30 GeV to 24 GeV would equalize the SX and FX power consumption and allow for parallel operation. Tests at 24 GeV for slow extraction a factor of 2 larger ripple compared to the 30 GeV operation.

The 24 GeV operation looks appealing in terms of power consumption, however clearly the noise on the power converters seem to be of high concern. Investigations should be done to understand if a reduction of the noise could be achieved or compensation schemes could be applied.

<u>Extraction for mu-e conversion</u>

The COMET experiment searches for a coherent muon-to-electron transition using as primary beam the proton beam from the MR. The experiment plans two phases, depending on the maximum available beam power. Currently the beam line and detector building are under construction at the hadron facility.

A pulsed bunched proton beam from MR at 8 GeV will be sent to the experimental target in a fast slow extraction. Bunches separated by 1.1 μs are needed to keep the experimental background as low as possible. The proton extinction between the two filled buckets should be better than 10^{-9}. The primary proton energy of 8 GeV is chosen to reduce the antiproton background.

Finding

Projection for the experiment phases:
- Phase I, beam power 3.2 kW at 8 GeV. 110 days starting FY2017.
- Phase II, beam power 56 kW at 8 GeV, 232 days starting FY2019-2020.

The 1 MHz pulsed scheme is realized by the linac chopper, removing the protons filling one of the two bunches of RCS and resulting in a RCS empty bucket. The MR receives then 4 bunches from the RCS, in 4 consecutive injections. The procedure was successfully tested but the residual proton population of the empty bucket proved to be too large (of the order of 10^{-7}). The necessary proton reduction is finally realized by adjusting the delay of the MR injection kicker, with the empty bucket placed at the start of the rising edge of the kicker pulse.

The injected proton beam could be successfully accelerated to 8 GeV.

The 8 GeV beam features a larger physical emittance compared to the 30 GeV beam, if produced without a different Linac painting to the RCS. Considering the relatively moderate intensity required by the experiment for Phase I, a different painting could be tested and lead to a smaller beam size. Measured emittances at 8 GeV with the FWS suggest that Phase I can be realized with the existing MR apertures. In particular the beam sizes at 8 GeV are comparable to vertical one measured at 30 GeV during the slow extraction.

Phase II is realized with the increased MR repetition rate of 1 Hz using the new MPS and higher intensity. The operation requires the use of dynamic collimator to eliminate beam halo during acceleration. The longitudinal emittance has to increase from 6 to 12 eVs, requiring the use of the second harmonic.

Comments and Recommendations

The required proton extinction procedure was successfully demonstrated, but without measurement of a slow extracted beam. The proposed solution of using the delay of the injection kicker proved to be clever and very effective.

The beam transverse size at 8 GeV seems to be adequate for the existing aperture for Phase I of the experiment, whereas new quadrupoles with larger apertures should be built for Phase II. In any case, a careful adjustment of the beam transfer between RCS and MR, as well as a careful tuning of the MR working point to avoid the half integer resonance should be pursued to reduce the sources of transverse emittance blow up.

The slow extraction process was simulated using the PTC-pyORBIT code and the space-charge induced tune shift doesn’t impact the extraction process significantly.

The Phase II stage of the experiment relies on the full upgrade of the MR, i.e., a faster kicker rise time, the second harmonic system, the faster pulse rate. The planning of the experiment has to closely follow the availability of these systems.

Demonstrate at 8 GeV the slow extraction with high beam power.

Re-measure the proton extinction with slow extraction and including the kicker rejection procedure. The result of theses tests should validate the necessity or not of other extinction procedures.

Investigate alternative cleaning procedure, like using the transverse damper as abort gap cleaner or the compensation injection kicker, in case the other means reveal to be insufficient for the proton extinction.

Impedance and Instabilities

RCS

Findings and comments

Simulations and beam studies were performed to demonstrate that enhancement of space charge by reducing the bunching factor and by reducing the beam momentum spread effectively suppresses broad-band instability caused by the RCS extraction kicker impedance. Computer simulation and some beam studies also indicate that a combination of the space-charge damping effect, manipulation of the transverse tunes along the acceleration ramp, and a finite, non-zero chromaticity enables beam intensity in the RCS to reach the equivalent of 1 MW beam power.

The demonstration of space charge damping on the broadband instability is a significant achievement. The work indicates that 1 MW RCS operation is possible with the present hardware configurations. On the other hand, and reduction of bunching factor enhances transverse space charge tune footprints possibly leading to resonance crossing and beam loss. Reduction of momentum spread also reduces conventional Landau damping of instabilities. It would be important to study in detail a balance of the effects of various contradicting mechanisms affecting the machine performance.

A so-called “cryptic beam instability” was observed in the RCS when the transverse tunes are equal. The mechanism of this instability, occurring when the transverse tunes are both 5.86, is not clear nor is the impedance source known. This phenomenon should be studied in details both theoretically and experimentally.

The Ionization Profile Monitor in the RCS was mentioned as an available diagnostic device. However, its performance is limited due to the space-charge effect and no data was shown at the review. Experimental measurements of beam instability or in general, the evolution of beam sizes along the cycle, could be better characterized by measuring in a continuous mode the beam size. The IPM would be a very useful device to improve the understanding of the physics phenomena observed.

The dominating beam coupling impedance in the RCS is identified to be the extraction kickers. The transverse impedance is determined to be about 10 times of the SNS ring kicker impedance. No systematic effort is made to compare and the kicker and its pulse forming network design between the RCS and other machines like the SNS ring pertaining to impedance reduction and design optimizations.

Every effort should be made to possibly reduce the impedance of the extraction kicker-PFN system. A careful comparison should be made to similar systems of other machines. An alternative design should be considered if the improvement is deemed to be significant.

R7: Compare the extraction kicker / PFN design of RCS and other similar machines. Consider an alternative design of the system for beam power at or beyond 1 MW.

MR

Findings and comments

Beam tests demonstrated that the new intra-bunch feedback system is effective to suppress intra-bunch oscillations. The system is now used in routine operation at J-PARC MR, together with help from the chromaticities, allowing attaining 265 kW beam power. The beam loss at injection is reduced from 350W to 170W. Since the 2014 summer shutdown, the vertical feedback systems are operationally switched off during acceleration due to lack of tuning time. More beam tests are planned for optimization of the feedback settings.

Adequate beam time should be allocated for tuning of the transverse damper during acceleration. Investigations should be pursued to suppress the closed orbit and avoid the saturation of the system in case of large orbit distortion at the pick-up location. The reason why the vertical feedback system is not working at the start of acceleration should be also clarified.

Measurement of the transverse beam coupling impedance in the MR was attempted based on evaluating the intensity dependence of the coherent betatron tune. The result was not conclusive due to the large system noise-to-signal ratio. Measurement of the longitudinal beam coupling impedance based on evaluating the intensity dependence of the coherent longitudinal quadrupole mode was not attempted and is planned in future runs. Further understanding of the measured impedance, in particular the difference between the injection flat bottom and the acceleration, should be carried forward.

R8: Measure with beam the transverse and longitudinal ring impedances in the MR.

<u>**RF systems**</u>

Linac RF

Findings and comments

Almost all 324 MHz klystrons powering the low energy part of the linac are getting close to the end of their expected lifetime. Four have already been replaced after 25 to 35000 hours because of arcing between anode and body, and 15 are approaching 40000 hours. This has been recently illustrated by a failing unit, which hopefully could be kept in use but at a reduced voltage. It should be expected that as many as 4-5 klystrons need to be replaced every year.

R9: Accelerate the procurement of spare, conditioned 324 MHz klystrons.

The 972 MHz klystrons powering the ACS section have been intensively used since only 2 years. The total of six spare units that will be available this year is appropriate. Investing regularly at a rate of 2 additional klystron per year should be adequate in the long term, until experience allows a better estimate.

R10: Explore the possibility of refurbishing used klystrons.

The HVDC klystron power supplies have been the source of long beam interruptions last year. That was due to the breakdown of rectifiers in the HVTR assemblies. The voltage dependence of the capacitance in parallel with each diode has been diagnosed as the cause of the fault. As a result, power supplies are being been refurbished with better performing capacitors.

Arcing in the 972 MHz circulators was due to loose RF contacts. All of them have been repaired before September 2014. Since then this phenomena has not been re-observed.

RCS RF

Findings and comments

After the refurbishment of cavity #6 with buckling-free MA cores during the summer shutdown 2014, only cavity #11 remains to be modified. In the absence of visible signs of performance degradation, its upgrade is being delayed by one year until the summer 2016.

The first attempts at accelerating the beam intensity corresponding to 1 MW beam power took place in October 2014 (run #57). Overcurrent trips of the anode power supplies of the RF amplifier set the limit of intensity. After suppression of feed-forward beam loading compensation on harmonics 4 and 6, a maximum of 6.87E13 p/p (~850 kW) was then attained. It was raised to 8.41E13 p/p (~1 MW) in December 2014 (run #59) by the combined effect of increasing the interlocked current threshold from 110 to 125 A and shifting the cavity tune from 1.7 to 2.1 MHz. This limitation should disappear after the summer 2015 shutdown, during which the maximum current capability of the anode power supplies will be increased by the installation of additional inverter units.

MR RF

Findings & comments

To reach the voltage required for acceleration in the MR with a 1.3 s repetition period without building new RF amplifiers, all cavities have to be replaced with new ones equipped with FT3L cores. The 9 cavities with 3 gaps each will ultimately be replaced by 7 cavities with 5 gaps and 2 cavities with 4 gaps.

This was comforted by the successful beam tests in the MR during the fall 2014 of the first 5 gaps cavity. Series fabrication of the 8 other FT3L-equipped cavities is in progress in view of installing 4 of them during the summer 2015 and 4 during the summer 2016.

A second harmonic cavity is in construction, using air-cooling and Finemet cut cores. Its installation in the MR is planned in 2017.

A half-gap Fluorinert-cooled cavity has reached nominal characteristics on a test bench, bringing this development to a successful completion.

The Committee congratulates the team that developed and built the Fluorinert-cooled cavity prototype. This technology can hence be considered as a valuable alternative to water-cooling.