Report from the 17th Meeting of the Accelerator Technical Advisory Committee for the Japan Proton Accelerator Research Complex (J-PARC)

March 1 - 3, 2018
J-PARC Research Building
Tokai, Japan

Introduction

The Accelerator Technical Advisory Committee (ATAC) for the J-PARC Project held its seventeenth meeting March 1 to 3, 2018, at the J-PARC Research Building in Tokai, Japan.

The ATAC members participating are: Alberto Facco (INFN), Simone Gilardoni (CERN), Alan Letchford (STFC), Subrata Nath (LANL), Michael Plum (ORNL), Thomas Roser (BNL, Chair), Toshiyuki Shirai (QST) and Robert Zwaska (FNAL). Jie Wei (MSU) could not attend this year's meeting. Former committee member Akira Noda (QST) attended as observer.

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.

J-PARC has now operated successfully for a number of years as a scientific user facility with world-leading performance and significantly improved availability. The beam power for MLF operation has reached again 400 kW and further power increases depend on the neutron target performance. The beam power for MR NU and HD has reached new record levels of 475 kW and 50 kW, respectively. As the J-PARC user facility becomes more mature, attention should be given to maximize productivity by minimizing the time spent on machine start-up and beam tuning.

R1: Explore opportunities to reduce the time spent on machine startup and beam tuning, and present these efforts at the next ATAC.

The MR beam power for neutrino production has steadily increased over the last few years and reached a new record of 475 kW. A major upgrade effort is underway to increase the beam power further to 750 kW and eventually to 1.3 MW by reducing the MR cycle time and increasing the beam intensity in the MR. The installation of the new MR power supply that is required for the reduced cycle time has started and the design of the remaining elements of the power upgrade is very advanced. This MR beam power upgrade effort might benefit from an enhanced level of coordination within J-PARC and documentation in a Design Report. To keep the T2K neutrino experiment internationally competitive it is critical that the MR beam power upgrade is implemented as soon as possible.

R2: Implement the MR fast extracted beam power upgrade as soon as possible.

J-PARC accelerator overview and projections

The J-PARC facility has now achieved a status of maturity where it can serve its various users with more consistent beam. Beam power was still limited due to issues with the MLF target and MR slow extraction target. The RCS has demonstrated 1 MW equivalent beam to the MLF and operated above 500 kW, but operation over the last year has been limited to 400 kW. The MR has delivered 475 kW to T2K, which is equivalent to more than 750 kW with the future MR power supply upgrade. The MR has also delivered 50 kW of slow extracted beam power and is ready for 50+ kW operations when the target limits are lifted. J-PARC has now placed greater priority on operations and reliability to fully exploit the existing capabilities, while still working on facility upgrades. This priority has been demonstrated through availability of near 90% for all the machines, excepting a single long-duration with an electrostatic septum in the Main Ring.

RCS for MLF:

- The RCS has proved 150-400 kW to the MLF in the last year, limited by the MLF target capability, while also further demonstrating that the RCS is capable of 1 MW and ready for operation when the MLF target is capable. J-PARC is preparing plans for increasing beam power to 500-1000 kW over the next few years.
  - 3599 hours of beam delivery (a substantial increase over prior year) were achieved out of 3863 scheduled for the MLF in JFY2017 to Feb 21. The downtime remained very low, achieving an availability of 93.2%, exceeding the goal of 90%.
  - 1 MW remains essentially demonstrated, but awaits a MLF target that can handle this beam power.
  - For the near term, operation will be limited to 400-500 kW until summer, when a target capable of 500-1000 kW will be installed. J-PARC will "explore" higher beam powers over the next few years and targets to approach 1 MW operation – a process which will be implemented in such a way to reach higher power, but maintain high availability.
  - While operating at lower power, single-bunch operation has been maintained – a mode that is more useful for some MLF experiments.
- 1 MW equivalent beam operation was further affirmed this past year.
  - Studies continue to demonstrate that 1 MW is available for MLF. Refinements are to limit losses and improve availability.
  - A 1 MW test of the target is being planned on the present operating target prior to the summer outage. This test is to inform future target designs.

MR with fast extraction for neutrinos:

- Beam power increased slightly to 475 kW in JFY17. Further beam power improvements will be possible with either replacement of the MR magnet power supplies (few years from now) and/or enhancements to the machine allowing higher beam intensity.

Assigned hours were limited due to sharing with the Hadron Facility and substantial accelerator tuning and study time.

  - Beam power to T2K increased from 470 kW to 475 kW. This beam intensity is equivalent to 900 kW if the cycle time were 1.3 s, instead of 2.48 s.
  - 1356 hours of beam were delivered out of 1528 assigned hours in JFY2017 to Feb 21, for an availability of 88.7%, near the 90% goal and substantially greater than the previous year.
  - There continues to be potential for modest beam power increases before the power supply upgrade. The mid-term plan cites >480 kW in JFY18 forward.
- J-PARC has begun implementation of a plan to reduce the cycle time to 1.3 sec as its primary path to achieving more than 750 kW in the MR. This is the most straightforward path to upgrading the MR fast extraction program and the Committee strongly supports it.
  - MR RF cavities are now fully upgraded to provide more voltage.
  - Building construction for the power supplies has started. Two buildings are complete and the third building will be completed in the next few months.
  - A prototype of the power supply model has been operating in the MR. A "first article" of one of the production supplies is being installed and will be tested with a spare magnet.
  - Further procurement of the power supplies is on hold pending funding. With the present schedule, the power supply upgrade will not be available for beam until JFY2022. Therefore, it is imperative to receive funding as early as possible for the power supply upgrade to avoid any delay.
- A new program of modest improvements to the MR could result in increased beam intensity. When combined with the power supply upgrade, 1.3 MW would be available from the MR for fast extraction. These improvements could start in parallel with the power supply upgrade. The mid-term plan has been updated with a gradual rise to 1.3 MW in JFY2028. The Committee considers this schedule conservative and encourages J-PARC to advance planning of these upgrades in addition to the power supply upgrade.

MR with slow extraction to the Hadron Facility:

- Beam of up to 50 kW was delivered to the Hadron Facility in JFY17. Further improvement are planned towards 100 kW with future targets in future years.
  - 972 hours of beam were delivered out of 1509 scheduled, for an availability of 64.4%, less than the J-PARC goal of 90% availability. The downtime was predominantly due to failure of the electrostatic septum.
  - An improvement in the timing sequence of the MR allowed a shorter cycle with the same 2 s extraction period, increasing the average power on target while not increasing the intensity in the MR or instantaneous extracted beam power.
  - The mid-term plan quotes a goal of 50 kW through JFY2019, 70 kW in JFY2020, and >80 kW in JFY2022.
  - Recently, there were several periods of 8 GeV operation in preparation for the COMET experiment. This mode is anticipated to become a substantial fraction of the operating time as early as JFY2019.

J-PARC plans to operate the MLF for 176 days in JFY18 and operate the MR as much as funding allows electricity to be purchased. The split between FX and SX has not yet been determined. J-PARC has extended their operation cycle from 1.5 months to 3 months of mostly continuous operation, consistent with proven lifetime of their ion sources of 90 days.

Comments:

J-PARC responded to the 2017 ATAC recommendation 1: "Focus on addressing reliability issues at the J-PARC facility." Numerous investigations occur in the various machines. A pilot program has been started on fault prediction to potentially anticipate failures of particular devices. This is a worthwhile approach but may be challenging to make effective. Integration of the fault prediction systems with operational control systems may be advantageous. In addition to fault prediction systems existing fault statistics on the operating equipment can already be analyzed and used for developing an effective preventive maintenance program.

J-PARC has developed several strategies to maximize science output, with substantial achievements in the statistic of operational availability (generally 90% or better outside of the ESS failure). The Committee notes that hours assigned to user operation may be an area to gain, especially with the Main Ring. In JFY2017-to-date: the RCS assigned 70% of operating time to user operation (of which they were 93.2% available); the MR assigned 55% of operating time to user operation (of which they were 77% available). Now that the J-PARC accelerators have matured, the proportion of time assigned to user operation may be increased to further enhance science output.

R3: Pursue greater allocation of user time during operating periods, in coordination with user requests and machine development, to enhance science output.

J-PARC responded to the 2017 ATAC recommendation 3: "Explore the possibility of increasing the flexibility of MR operation to make more efficient use of the facility and serve more users." J-PARC experienced one opportunity to use such flexibility with the ESS failure during MR SX operation. J-PARC found that the other facilities and users were not flexible enough to make effective use of switching beam modes, and instead endured a 1-month outage of the Main Ring.

ATAC notes that the high-power operation of the future COMET experiment may be challenging and encourages beam studies. Furthermore, the Committee encourages discussing optimization of the experiment with the users in preparation. In particular, 3 GeV slow-extraction from the Main Ring could be explored. This energy may be advantageous for the experiment as it suppresses antiproton production. Without acceleration, the MR could also have a much quicker cycle, partially compensating for the loss of beam energy. Slow extraction at this energy could be challenging.

The available beam power from the J-PARC accelerators have frequently been limited by the capability of the target facilities (presently limiting MLF and MR SX). ATAC observes that the operation of the targets is all performed by separate organizations, and further that reviews vary

(NAC review for MLF, ad hoc reviews for neutrino and hadron). J-PARC may consider consolidating its target production organizations and reviews on a regular basis.

J-PARC asked for ATAC experience on methods and strategies to achieve high availability. The Committee notes that this field has developed on its own within the accelerator community with its own series of workshops (Accelerator Reliability Workshop) and body of knowledge. Some accelerator facilities have established groups within their accelerator operation organization that are responsible for reliability throughout their facility. In addition, the Committee notes some particular practices:

- Electronic work lists to collect and approve jobs and be prepared for planned and unplanned outages.
- Scheduling outages in advance to consolidate downtime requests and provide planning points (deadlines) for working groups.
- Collection and analysis of operations statistics is an entry point for optimizing the entire facility. Control systems must effectively capture data and make it accessible for analysis. Furthermore, analysts must be encouraged or tasked with finding results.
- Focusing effort on performance through the use of effective goals and tracking through dashboards and regular communication.
- Preventative maintenance according to well-planned schedules, and the tracking of deferred maintenance.
- Production of risk registries for individual machines, and a master list for the accelerator complex. Risks can be scored, and mitigations developed for the those risks with the most potential impact.
- Adopting a process of continuous improvement with spares of major components and prioritizing in their procurement and production.
- Regular, scheduled communication with users at various leadership levels.

Status of Linac and beam study results

Findings:

During JFY2017 the linac was run at 40 mA for user operation with rather high availability (>93%), improving performance from the previous year. Beam tests up to 60 mA have been successfully accomplished. No major issues appeared and several of the problems presented in the previous ATAC review have been fixed. Beam trips are still present – mostly from RFQ and BLM - worthy of further investigation with the goal of their elimination or reduction. Only two 10-hour long beam outages were reported, caused by the failure of a cooling water pump and of an anode modulator.

Beam studies have been carried on with valuable results and significant progress in beam power increase and beam loss reduction.

Recommendations from ATAC2017 have been properly addressed.

No issues were reported in the ion source, which could run continuously for about 3 months at 45 mA. 68 mA of stable beam at the linac input have been achieved in a 2-day development run.

The RFQ operation was stable and reliable, except for short trips - 15 per day on average – which could be manually recovered in about one minute. The problem was investigated and an increase of vacuum level during trips was observed, reasonably interpreted as caused by inter-vane sparks. Residual gas analysis showed the presence of hydrocarbon molecules the origin of which is not yet fully clear. The team attributed it with highest probability to back-streaming in the vacuum system rather than to sputtering from the carbon-made chopper scraper. RF conditioning and improvement of the vacuum by adding more pumping power will be pursued to reduce trip rate.

Comments:
The presence of a large amount of carbon in the chopper scraper, continuously hit and sputtered by the beam in proximity to the RFQ, might well explain the presence of hydrocarbon deposited on the RFQ interior, which might enhance sparking rate.

Although downtime from RFQ trips is still tolerable and rather constant with time, further investigation is advisable.

The planned development and installation of an automatic restart procedure, capable of minimizing downtime from the present ~1 minute per spark event to about 1s (thus to about 15 seconds per day), is highly recommended. The automatic procedure should be able to recognize and select only true spark events, in order to prevent unwanted restarts in potentially more destructive conditions.

R4: Develop and install an automatic restart procedure for the RFQ sparks.

DTL/SDTL: the only issue reported is a residual, non-critical multipacting in cavity S05A, sufficiently cured by means of periodic cleaning. The serious cooling water problems presented at ATAC2017 have been completely solved.

ACS cavities have run reliably with a trip rate that decreased with time down to a comfortable value of about 0.3 events per day.

Concerning the beam chopper, the long-term operational reliability after removal of the initial RF ringing problems have been demonstrated both in the linac and in the test stand. Scraper operation temperature, long term stability and beam damage have been tested and have shown to be fully compliant with the high-power operational goal.

Additional Bunch Shape Monitors (BSMs) have been installed in the linac, improving precision measurements during beam studies. A new WSM based on carbon nanotube (CNT) wire was tested with promising results. A CNT wire is expected to substantially increase the wire lifetime and is planned to replace all carbon wires.

The origin of frequent beam interruptions from MPS caused by BLM signals was finally clarified and attributed to a faulty BLM, which produced spurious signals. Its replacement or repair should considerably reduce the related downtime. Redundancy in BLMs should be the rule to increase reliability of such measurements, which are in many cases critical for machine and personnel protection.

R5: Replace the faulty BLM without delay.

Findings:
Klystrons performed within and above expectations in terms of average lifetime. Regular replacement of old elements and a proper stock of spares allowed achieving high availability of the RF system. A klystron test stand was built to perform off-line conditioning before installation in the linac to save time.

Comments:
The Committee encourages the team to continue keeping a sufficient number of spare klystrons to cope with possible multiple failures of aged units, which are now numerous in the linac and might be approaching their lifetime limits.

In general, a significant progress in linac reliability from the previous ATAC review is recorded and actions for further improvement have been pointed out.

Findings:
A rich program of beam studies was carried out in the linac. A better knowledge and optimization of the machine at different beam current conditions was reached; long lasting hardware problems have been understood; new hardware was installed and tested; beam transport was further refined to reduce beam losses. High current beam with low losses and suitable for injection into RCS was finally achieved. Several important results have been reported, among them:

- Resolution of the BLM misfired interlocks;
- Verification of new on-line hardware;
- Valuable progress in the knowledge of the beam parameters and improvement of their measurement methods;
- Improved comprehension and mitigation of the IBSt losses, and verification of the effectiveness and reproducibility of ACS tune at T=0.7;
- Beam dynamics simulation of the RFQ and linac using realistic input beam parameters measured at the ion source test stand, and cross check with the beam parameters measured in the linac where possible;
- Achievement of 62 mA at MEBT1 (a J-PARC record) and of 55 mA at the end of the linac with nearly 100% transmission after MEBT1;
- Achievement of beam conditions suitable for injection with high current in RCS.

Problems have been reported that require resolution and further investigation: emittance growth is still present in MEBT1; hot spots caused by beam losses exist at cavities ACS07 and 08 even after beam optimization; asymmetry in the measured beam profile was observed and not fully understood as well as discrepancies between beam simulations and measurements.

The beam study activity will continue during 2018 with the main goals of improving the MEBT1 and MEBT2 settings and of performing the first trial injection of 60 mA beam in the RCS in July 2018.

Comments:
The steady progress being achieved in linac performance, reliability and knowledge is remarkable. The Committee encourages the team to continue investing time in deepening the knowledge of their machine and its capabilities, in view of improving user operation and of becoming ready for future upgrades.

Status of RCS and beam study results

Findings:
Between January and June 2017, the RCS delivered 150kW to MLF due to target limitations. During the summer 2017 shutdown the MLF target was changed and the power increased to 300 kW. Since January 2018 the MLF has been running at 400 kW achieved by injecting a single 800 kW-equivalent bunch into the RCS. Availability has ranged between 98% and 99.6% averaging 99.2%.

Tritium was detected at the level of a few Bq/cm^2 in a dry scroll pump so a booth for maintenance has been installed. The Hybrid Boron Carbon (HBC) foil development has been moved from KEK to J-PARC following the retirement of the KEK expert. R&D towards a robust HBC foil is continuing with the new foil design having been tested for 10 days so far.

Workers' collective and peak radiation doses have been further reduced compared to previous years with 1.08 person-mSv recorded in the 2017 shutdown and no individual dose exceeded 100 μSv.

As MLF running accounts for most RCS pulses, reducing beam loss in this mode has been the priority. 200 π mm mrad anti-correlated painting gave very low but non-zero injection losses. Numerical simulations could well reproduce the remaining loss due to 3rd order resonances excited by the sextupole component of the bump magnet field. A new operating point further reduced the beam loss by half. For MR mode running a smaller 50 π mm mrad correlated painting scheme results in the smallest extracted emittance. However, when operating in MR mode with the same tunes as for MLF mode, the smaller emittance leads to a space charge tune shift, which crosses an integer resonance with subsequent emittance growth. The correction quadrupoles originally only compensated for the injection bump magnet edge effects during the first 1 ms but new power supplies installed in summer 2017, as endorsed by the last ATAC, now allow for tune changes out to 12 ms avoiding the integer resonance and reducing the vertical emittance by almost a half. Further power supply upgrades planned for 2018 will give even larger tune variation and reduction of the emittance growth. Installation of bipolar sextupole power supplies in 2017 now allows for chromaticity correction and suppression of an instability caused by the kicker magnet impedance.

Comments:
The Committee continues to be highly impressed by the quality of the RCS simulations and the degree to which they agree with measurements. The understanding of the RCS beam dynamics has resulted in quite remarkably low beam losses for such a high intensity machine.

<u>Status of MR</u>

Findings:
During the last year, the Main Ring delivered for the Fast Extraction (FX) operation up to 475 kW and about 50 kW for the slow extraction (SX) operation. The FX had a beam availability of 89% whereas the SX beam availability was 64%.

The low availability of the SX was caused by the failure of one of the two extraction Electro-Static Septa (ESS), which was damaged by the beam. Six wires were broken and one, despite the spring removal system, unfortunately remained in contact with one of the electrodes causing a short circuit. The septum needed to be replaced with a new one made of Ti, after a low-power running period when the SX delivered 37 kW instead of 44 kW. In total 28 days were needed before resuming beam operation, days that were lost to both the FX and SX program, since it was not possible to operate the neutrino line, which was in maintenance mode with the superconducting section at warm temperature.

The SX power was increased during Jan.-Feb. 2018 to about 50 kW with a beam availability of 87%, including some experimental facility downtime. The cycle length was reduced from 5.52 s to 5.2 s to increase beam power. Now the maximum beam power is limited by the hadron target and not by the MR. The regulated limit for SX operation is set at 53.4 kW, the limit for PPS is 52.3 kW and 51.8 kW is the MPS limit. The regular operation beam power is then set beyond 50 kW. In the same period, SX tests at 8 GeV in preparation for the COMET experiment were successfully performed.

In the period Oct-Dec. 2017 the beam power of the FX could be increased from 150 kW to 450 kW steady operation, reaching in December finally 475 kW with total losses along the cycle of 0.8 kW. After the problem with the SX septum, and the summer shutdown, a long recovery period was needed before re-establishing high-power operation due to poor vacuum, in particular related to the outgassing of the new septum and the rearrangement of some collimators in the injection region. No instabilities were observed during this period of time, but the large outgassing caused important localized losses from the beam directly interacting with the residual gas present in the vacuum chamber.

Significant progress was achieved towards the beam power upgrade. The FX kickers were upgraded for 1 Hz operation with an improvement of the 5 kicker chargers and pulse terminators. After the upgrade it is now possible to extract the beam practically at any energy with an emergency beam abort, e.g. in presence of large losses, without the need of accelerating the beam up to the flat top. The system proved to be effective in October when the beam was extracted by the abort system at intermediate energy due to excessive losses.

The collimators in the injection region were rearranged in view of future improvements to increase the total manageable power loss from 2.5 kW to 3.5 kW.

In response to the last ATAC recommendation, the brazing of the cooling circuit of the main bends was inspected, and no water leak or damaged brazing was found. Every main bending magnet has two water manifolds with brazing but only one is accessible. The main quadrupoles were not inspected because they have no brazing.

The mid-term plan for the upgrade had to be modified because of the lack of supplementary funding that was available in JFY2017 but not in JFY2018, with an important impact for the new MR PS planning. For this reason, and not to delay significantly the project, it was decided to fund the upgrade of the MR PS by reducing the machine operation period and some maintenance. Despite this, the construction of the MR PS buildings is well advanced with respect to the ATAC2017, with 2 of 3 buildings already completed and the third close to completion. Also, a module of the new power supply has been completed and will be tested soon.

Comments

The large residual dose rate measured during the rearrangement of the collimators indicated that it will not be possible to move the existing collimator a second time while in parallel installing new ones because the integrated dose to personnel would be too high. In this sense, it would be useful to explore the possibility of remote handling of the equipment, or to design the new collimators for easy interventions by robots or remote handling at least for some of the tasks required for the installation or maintenance, like cables disconnection, opening of vacuum flanges, etc..

Following the extraction septum accident, it appears that the MR cannot change easily the operation mode from SX to FX and vice versa for various reasons (HW availability, planning of user schedule, rescheduling of shift members). The status of the spare equipment for systems necessary for minimum operation should be reviewed to avoid, as in this case, further delays due to the unavailability of spare equipment on site and possible damage that could occur during transport as was the case for the septum.

The Committee recognizes the importance of a timely implementation of the new MR PS in order to go beyond the 0.5 MW beam power and hopes that sufficient funding could be made available in the near future. The Committee expresses some concerns about the decision to reduce the funds available for the machine maintenance to sustain the MR PS upgrade possibly risking reduced availability or efficiency of critical systems.

<u>Beam study for MR fast extraction</u>

Findings:

Studies in the MR were concentrated on the further understanding and reduction of the beam losses appearing during operation at 475 kW. Most of the losses, of the order of 800 W, are concentrated during the injection process and at the beginning of the acceleration, and well localized in the collimation region.

Losses were minimized by:

- optics correction;
- main resonance compensation guided by driving terms measurements;
- instability damping by intra-bunch damper and chromaticity;
- space charge effect mitigation by introducing a second-harmonics;
- dynamic tune tracking to compensate bunch train tune shift;
- collimator improved settings.

All these parameters were re-optimized, and losses minimized at each intensity increase, considering that high power studies were possible only after the recovery of a good vacuum following the summer shutdown.

Particular attention was given the residual dose rate, measured after the 470 kW operation. The radiation survey showed doses below 300 uSv/h in the region outside the collimation area, whereas the maximum dose rate was found in correspondence of the QDX089, above 10 mSv/h.

Tests were done in Dec. 2017 with 480 kW beam. Losses show that the optimization of the same parameters as for 475 kW operation should be repeated, but with new longitudinal coupled-bunch instabilities observed. The instability is driven by the impedance of the main RF system and seems to be mainly dipolar (n=8) with some residual quadrupolar oscillations. A longitudinal feedback system is under development, by using one main RF-system cavity to damp the instability. Preliminary tests at low intensity are promising: beam dipolar oscillations induced by an external excitation could be damped by the new system.

The rearrangement of some collimators of the 1-stage system was done in preparation of a further upgrade. The system was capable of handling 2.5 kW losses, reduced temporarily with the current arrangement to 2 kW. This is compatible with current operation and the final upgrade to 3.5 kW. After the rearrangement of the collimators, the optimization of their tilt angle led to an improvement in beam losses. The closed orbit proved to be sufficiently stable, requiring a re-optimization of the collimator alignment only after some weeks.

Some further improvement of beam losses was observed during a test limited to two bunches (450 kW equivalent), where a tungsten beam scatterer was used to change the halo momentum distribution and mimic a two-stage collimation system. The interaction with the Tungsten scatterer increases the momentum spread of the halo beyond the longitudinal aperture of the MR, reducing the overall beam losses and localizing them at the collimator. The scatterer has been used also as halo monitor.

Comments:

The losses during the injection flat bottom seem to be under control, but losses appearing during the start of the acceleration are not fully understood yet. Since better resonance compensation, better optics corrections, or any other technique already tested seem to provide some loss improvements at every intensity step, it would be interesting to further explore the interplay between the transverse and the longitudinal planes, in particular at the start of the acceleration ramp. For example, an increase of the direct space charge tune spread at the beginning of acceleration due to bunch shortening might cause transverse losses that are not necessarily in the large dispersion regions. Also, any relative RF-phase between the first and the second RF harmonics, or the way the second harmonics voltage is reduced before the full acceleration, could induce a bunch shape change that could affect the space charge tune shift.

Particular attention should be given to the closed orbit, beam mean radial position or longitudinal oscillations during the transient period at the very beginning of the acceleration ramp. Furthermore, the resonance correction might be less effective at start of the acceleration, if the gradient of the correcting sextupole is not following the ramp or if the optics, i.e. the relative phase advance between the different sextupoles, is changed by any transient in the main or trim quadrupoles.

The use of octupoles and sextupoles certainly help to increase the transverse Landau damping and, together with the intra-bunch damper, reduce the appearance of transverse beam instability. However, the fact that the octupole strength cannot be adjusted to follow the beam rigidity might limit their effectiveness. If their effect is beneficial, it would be important to further quantify their effect, in terms of non-linear chromaticity, non-linear horizontal/vertical coupling and synchro-betatron coupling.

The strategy for the upgrade of the collimation system should be clarified. It is not clear if the current system is used as a two-stage collimator in the current configuration and how a further rearrangement of the collimators could increase the absorbing power up to 3.5 kW. Furthermore, the procedure to optimize the relative alignment of the different collimators, including the optimization of the tilt angle, seems to be pretty complicated. This requires the independent optimization of every single collimator with respect to overall losses, but without a clear definition of the hierarchy of the collimators with respect to a variation of the available aperture during the optimization process.

It would be interesting also to explore the possibility of an automatic alignment procedure, by introducing a BPM attached directly to the collimator jaws to provide online the relative position of the absorbing material with respect to the beam closed orbit.

Status of MR slow extraction

Findings:
The SX had a particularly low availability during the 2017 run related to a failure of one of the two electrostatic septa, the SUS-ESS1. Six wires were damaged by the direct impact of the beam, caused probably by a wrong (positive) setting of the horizontal chromaticity during the machine setting up. One of the wires remained in contact with one of the electrodes, causing a short circuit and thus requiring the removal of the septum.

A spare septum was transported from the Tsukuba campus and installed, but unfortunately a damage occurred most probably during the transport, and the septum suffered from too large dark currents after a sparking at 80 kV. The new septum had to be removed, and the septum SUS-ESS2 was moved from its original location to the SUS-ESS1 slot. This action improved the losses at the magnetic septum during the extraction operated with a total reduced transverse kick with respect to nominal operation.

About 1 month of physics was lost due to the septum replacement, and after a first start with delivered beam power limited to 31.2 kW, a moderate increase to 37.5 kW was possible before the summer shutdown. The extraction efficiency was 99.3% during the 37 kW run, compared to 99.5% of a nominal running period at 44.5 kW. Some compensatory measurements were taken to avoid any further erroneous setting of the machine with high intensity beam.

The new Ti septum was modified before installation with the introduction of a baffle to avoid any possible contact between a broken wire and the electrodes, and RF contacts were also added to improve the longitudinal impedance. The septum was installed during the summer shutdown after returning the SUS-ESS2 at its original slot. The performance of the new Ti septum is very similar to the Stainless Steel one with the advantage of an expected reduced residual dose rate due to the different material.

The extracted beam power was initially 10 kW, and then increased to 33.5 kW after the reduction of the cycle length from 5.52 s to 5.20 s while keeping a constant spill duration of 2 s. Then the beam power was further increased first to 45 kW and then to 50 kW, close to the regulated limit of 53.4 kW for operation. Tests were done also at 51.09 kW.

During the period Jan.-Feb. 2018, the SX provided beam with a 93% efficiency, including some tests of the extraction at 8 GeV for the COMET experiment. The beam could be extracted with an efficiency of 97.3% that could be eventually improved after a beam-based realignment of the extraction septa. Extinction tests were done to eliminate satellite bunches that would reduce the efficiency of the COMET experiment. The injection kicker timing is set to place the falling edge of the kicker in the empty gap between the main bunch and the first satellite bunch. The SX extracted bunched beam is then measured in a secondary beam line of the HD. An extinction factor (defined as the ratio between the beam present in the empty buckets between two consecutive bunches and the bunch intensity) of 1.7e-8 could be reached. A further improvement down to 9.9e-11, sufficient to fulfill the requirement of the COMET experiment, could be possible by rejecting in the experimental data acquisition the first part of the spill, where some parasitic beam from the fourth injection is still present.

A new beam power record of 62.8 kW-equivalent was also reached before the end of the run.

Comments:
The Committee wants to congratulate the MR team for reaching the 50 kW beam power for the SX nominal operation and for achieving 62.84 kW-equivalent during the test period.

R6: Consider implementing mechanisms to avoid machine settings that can damage equipment such as the ESS

<u>Review of the MPS</u>

Findings:
In response to two events (collimator collision and vacuum leak due to beam impinging on a flange), the ATAC2017 Committee recommended to review the whole J-PARC Machine Protection System, and to present the result at the next ATAC. During the ATAC2018 meeting the two events were reviewed. The collimator collision event was not due to a problem with the MPS system, but rather with the collimator control system itself. It is not clear if there is still a problem with the collimator control system. The vacuum leak event was caused by electrical noise, which caused the fast extraction septum magnet current to drop before the end of the energy ramp, which in turn drove the beam into the vacuum flange. The abort kicker system in place at the time was not capable of aborting the beam before the end of the energy ramp. The abort kicker power supply has now been upgraded, and the MPS system has also been upgraded, so that the abort kickers can now fire at any time during the energy ramp. This particular MPS vulnerability has thus been mitigated.

The Committee also was told about another event on January 20, 2018. In this case two simultaneous failures occurred (a failure of a pulsed power supply to energize the magnet that deflects beam from the RCS into the MR beam line, and the FCT that is supposed to detect that unintended beam is being sent to the MLF). In this particular case the response has been to increase the width of the FCT gate signal to make it better able to detect this type of equipment failure, but at the expense of making it more susceptible to electrical noise. A module to detect an event error in the timing system has been designed and is now under evaluation. An output monitor for the pulsed bend magnet is also under discussion.

Comments:
To date, all the MPS work has been reactive rather than proactive. The Committee renews its recommendation to proactively review the entire J-PARC MPS system to find weak points and address them before they manifest themselves and cause other equipment failures and down time.

R7: Proactively review the entire J-PARC MPS system to find weak points and address them before they manifest themselves and cause other equipment failures and down time.

Any new equipment or major modifications to existing equipment needs to be reviewed. Machine protection, set points, procedures to control the critical set points, equipment self-protection, interlocks, and impacts on operations should all be closely reviewed, approved, and documented prior to installation.

R8: Establish a process to review, document and approve all new equipment as well as any significant modifications to existing equipment before installation or implementation of the modification.

<u>Cabling and grounding at J-PARC</u>

Findings:
Last year, noise issues were encountered in the three MR power supplies. They were subsequently resolved by adding extra grounding. In view of the above, the Committee recommended to 'Examine grounding scheme, implementation and electromagnetic compatibilities.' Cabling schemes for linac, RCS, main magnets in the MR, pulse magnets in the MR, RF systems in the MR, and MR power supplies were examined. However, it appears that a systematic process has not yet been initiated to implement a uniform grounding policy to uncover any possible or unidentified incompatibilities. As a result, future occurrences of grounding problems would have to be dealt with on a case by case basis.

Comments:
Such an approach could run the risk of incorrect cabling and/or grounding induced interruption or subpar operational performance. The situation might even be further aggravated by a loss of corporate knowledge that an attrition of experts would entail. Though resource intensive, it would be prudent to enforce the implementation of a machine-wide grounding policy. This is especially important for new equipment installation and ad-hoc modifications to the existing electric circuits. It should have potential payoff by avoiding subpar performance of individual equipment.

R9: Document the policy on grounding and electromagnetic compatibility (noise avoidance) and have personnel trained in this policy.

MR upgrade: New power supplies

Findings:
In order to achieve the design goal of 750 kW the MR cycle time has to be reduced from 2.48 s to 1.32 s. This requires the bending magnet power supplies to be upgraded from 3 kV, 6000A to 6 kV, 6000A. To avoid unacceptably large power variation on the AC grid (> 100 MVA) energy recovery in capacitor banks is necessary.

The new power supply design has 6 H-bridge choppers in series with each chopper having its own capacitor bank module. Two capacitor bank modules are connected to AC grid transformer/rectifiers and four are floating. The total capacitor bank stored energy is 4.2 MJ while the magnet stored energy is 1.8 MJ. The capacitors are a dry film, self-healing design encapsulated in non-flammable epoxy. The manufacturer guarantees 10 years of operation under 1.3 s cycle conditions with less than 5% capacitance loss for 10^8 cycles. Each capacitor bank module consists of 8 frames with each frame containing 3 units of 4 capacitors each. One container houses 2 capacitor bank modules.

Every unit is protected by an independent fuse. Testing has demonstrated a fuse arcing time of 250 µs for the full-scale PSU. No bursting or deformation of the capacitors was observed during the short circuit test. The use of non-flammable materials in the capacitor design suggests that no compartmentalization of the capacitor frames is required.

The three new power supply buildings are constructed, and one has had the infrastructure completed. High power testing of the first power supply will begin later this year.

R10: Consider getting advice on the operational safety from external experts (e.g. CERN) before putting the new power supply into service.

Toward 1.3 MW for neutrino production

Findings:
There is a long-range plan to upgrade the MR beam power to 1.3 MW by decreasing the cycle time to 1.16 s and by increasing the protons per pulse to 3.3e14. Some hardware changes are needed: the MR collimator capacity will be upgraded from 2 kW to 3.5 kW, two more cavities will be added to the accelerating RF system and the anode supplies will be upgraded. Also, six quadrupole magnets will be replaced with larger-aperture versions and the BPM system will be upgraded for higher resolution. In addition, the transverse and longitudinal feedback systems may need an upgrade for higher power, and the injection kicker cooling may need an upgrade for higher capacity. Simulations are being performed to determine the optimum operating point, to study space charge effects, etc.

Comments:
Overall the 1.3 MW upgrade is still in the early stages. The Committee does not see any insurmountable issues and is satisfied with the progress to date.

Toward 1.3 MW for NU: Hardware upgrade and instability issues

Findings
The J-PARC team is steadily pursuing R&D toward the beam power of 1.3 MW for the neutrino experiments.

The simulation study of the new magnet power supplies shows that the 1.16 sec operation is realistic. The derating factor is less than the threshold number of 0.8.

The RF upgrade for the 1.3 MW operation is planned. 11 4-gap RF cavities are used for achieving the accelerating voltage of 600 kV. To accelerate 3.34×10^{14} ppp in the MR, the 5-gap cavities are converted to 4-gap cavities to avoid needing big changes of the electrical power equipment.

To reduce the beam loss near the FX area, six QDTs will be replaced with the large aperture quadrupoles.

The new 3.5 kW collimator system is designed for 1.3 MW operation.

The longitudinal feedback damper was developed to suppress the longitudinal coupled-bunch instability and it works well.

The temperature rise of the kickers was a risk for high beam-power operation. New injection kickers and FX kickers were installed, and the temperature rise of the kickers is acceptable.

The transverse feedback damper was developed to suppress the transverse instability in the MR. It works up to 2.4×10^{14} ppp but the damping rate needs to be improved for 1.3 MW operation.

Comments

The beam studies in the MR is producing many good results but is not completely coherent and coordinated. The Committee suggests that, toward the 1.3 MW beam power goal, all required R&D subjects from the Linac to the MR, their status and the schedule should be summarized in a design report. The following subjects should be included in the report:

- Estimation of the beam loss improvement by replacing the QDT155 with large aperture quadrupoles for the 1.3 MW operation.
- Reasons for the performance limitation of the current BPMs, reasons for the need for improvements, and improved methods for the BPMs for the 1.3 MW operation.
- Injected beam matching studies at the MR and beam loss studies during the first part of the acceleration for the 1.3 MW operation.
- Risk analysis and MPS for the 1.3 MW operation.
- The damping rate of the transverse feedback system depends on the chromaticity of the MR. The operational parameters of the MR should be optimized for the overall design.