Report of the 18th Meeting of the Accelerator Technical Advisory Committee for the Japan Proton Accelerator Research Complex (J-PARC)

February 28 – March 2, 2019
J-PARC Research Building
Tokai, Japan

The Accelerator Technical Advisory Committee (ATAC) for the J-PARC Project held its eighteenth meeting from February 28 to March 2, 2019, at the J-PARC Research Building in Tokai, Japan. The ATAC members participating are: Wolfram Fischer (BNL), Simone Gilardoni (CERN), Mats Lindroos (ESS), Michael Plum (ORNL), Toshiyuki Shirai (QST), John Thomason (STFC), Sheng Wang (IHEP), Jie Wei (MSU, chair), and Robert Zwaska (FNAL) (Appendix 1).

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. In addition, the accelerator team responded promptly to the homework requests from the committee.

Executive Summary

Since the last ATAC review held in February 2018, J-PARC accelerator team has been steadily raising the beam power and machine availability, successfully progressing as a scientific user facility with world-leading performance. The Linac has been operating at an increased peak beam current of 50 mA. The beam power for MLF operation has increased to 500 kW with an availability of 94% and further power increases depend on the neutron target performance. The beam power for MR neutrino (NU) and hadron (HD) has reached new record levels of 500 kW with 86% availability and 51 kW with 83% availability, respectively. The MLF operated for 8 cycles (~176 days) similar to last year.

The J-PARC accelerator team has been persistently pursuing machine improvements and system upgrades within the limit of budgetary constraints. There have been focused beam studies and R&D efforts pertaining to J-PARC's upgrade missions including increasing the peak current and doubling the repetition rate of the Linac supporting both the RCS and a possible future experimental facility for nuclear transmutation; beam power ramp up of RCS beyond 1 MW that ensures a net 1 MW beam delivery to MLF after MR repetition upgrade as well as feeding future second target station; and staged beam power ramp up of MR to 1.3 MW meeting demands for NU upgrades, Hadron Hall extension, COMET-II, and g_μ-2/μEDM programs. Studies pertaining to heavy ion acceleration were not reported at this review.

The J-PARC accelerator team has addressed most of the 2018 ATAC recommendations. In particular, a task force was formed to address concerns on machine protection and possible compromise to accelerator availability and system reliability. A report was also given at this review on the cabling and grounding across the J-PARC accelerator complex. The committee commends the J-PARC team on their dedication and vigor addressing pressing issues.

In the following, we summarize the main recommendations of the 2019 ATAC. Each of the eight recommendations (**R1** – **R8**) will be elaborated multiple times across the main body of this report following committee findings and comments. The order of the main body of this report follows the 15 talks (Appendix 2) and 3 homework assignments presented at this review.

J-PARC is a large-scale accelerator-based platform that supports both discovery research and user applications. Such a multi-purpose facility typically has a life span over 40 years, during which constant updates and rejuvenation are necessary. It is now about 10 years since the start of operation of J-PARC, and deterioration is becoming evident in components of the Linac, RCS and MR. Some electronic components have become obsolete and the control system will soon have to be updated. As the J-PARC budget is limited there will inevitably have to be an initiative to prioritize projects in a quantitative and defensible manner. As the facility becomes older a substantial amount will need to be invested in sustainability. J-PARC will have to support this sustainability programme and allocate an appropriate budget, simultaneously with the new beam power upgrade. This will inform management decisions and provide documented rationale for why decisions are made. A risk-based approach is recommended, as is looking forward at least 5 – 10 years: some sustainability issues can take 10 years to address.

R1: Establish a robust and uniform prioritization process and develop preventive maintenance plans for dealing with deterioration of equipment and utility infrastructure in all areas of the J-PARC accelerators, taking particular note of equipment of single-point failure, systems that may become obsolete, and devices of long lead-time replacement.

The ATAC2019 committee recognizes that the task of proactively and comprehensively reviewing the machine protection system (MPS) is a large one that will require significant manpower. However, the committee also believes that this effort is important and will ultimately benefit the J-PARC facility, especially as the beam power is increased and the MPS weak points cause increasingly severe consequences.

R2: Continue the effort to proactively and comprehensively review the machine protection system to locate hardware systems that are not adequately protected. Implement an MPS review process for all new hardware that is consistent throughout the J-PARC organization. Include analyses of how individual systems can interact with each other in ways that create unsafe conditions.

Run permit systems are commonly used at other accelerator facilities to automatically limit the beam pulse length and/or the beam repetition rate when the accelerator is lined up for beam delivery to low-power destinations. The committee suggests that J-PARC consider implementing such a system to reduce the probability of human-error caused equipment damage. A run permit system would become even more valuable to J-PARC as the accelerator reaches for ever-higher beam powers.

R3: Complement the machine protection system with a run permit system pertaining to modes of beam destination and allowed beam structure, duty factor, and beam power setting to minimize potential human errors.

Actual hours to the Neutrino and Hadron user areas continue to be challenged by several factors. Funding has limited the time available to operate. Despite the efforts of the J-PARC accelerator team and progresses made, startup and tuning continue to consume a large fraction of the time. This year, there was also a three-month suspension of MR running after the summer shutdown while maintenance was carried out at the Hadron Facility and at Kamioka. Finally, there was 10 days of beamtime lost to all users due to an atypical transportation of a spent target. The committee recognized that machine development is vital and that maintenance days are required. However, the MR sum of 2101 hours scheduled out of 5017 calendar hours in JFY2018 is low compared to other facilities, especially when no significant upgrades are being implemented. Further gains are possible for the MLF, and especially the MR users.

R4: Seek to maximize operating periods at both the MLF and MR, and maximize allocated user hours within those periods by measures including coordinating the down time requests for different areas of the facility.

In accelerator facilities of new construction or with major system upgrades, system requirements with design specifications and interface criteria are typically documented thoroughly. Along with these documentations, acceptance criteria are developed and specified with major procurements to meet performance expectations.

R5: Strengthen verification of acceptance criteria specifications and documentations on major subsystems; for example, specify and measure the new MR power supply ripple throughout the planned operating cycles.

Longitudinal coupled bunch instabilities appear for operation at about 500 kW in MR. In addition, the current of the anodes lacks margin to be able to significantly increase the power. The instabilities are to be damped by a spare cavity used as longitudinal damper. The functioning low-level RF (LLRF) system should be examined especially for transient beam loading compensation. For higher beam intensities, it should be studied if quadrupole modes appear in addition to dipole modes.

R6: Improve the understanding of MR longitudinal instabilities observed at powers above 450 kW, with the ultimate aim of implementing an active feedback system either on the cavities themselves or as longitudinal damper.

The committee is concerned about the cost/benefit analysis of the new RCS injection area shielding. The cost will certainly be high. However, the benefit was not well quantified. The cost/benefit may be favorable – it's just that it was not evident to the committee based on the information presented. The committee suggests that the case for installing the new shielding design should be reviewed to make sure that the new shielding can be justified.

R7: Make a detailed installation plan for the new RCS injection area shielding design that includes the expected total radiation dose to the installation team.

Time for beam studies seems to be very limited and that is slowing progress and limiting user hours. With the drive for higher intensities it will be essential to perform more beam studies to assure stable operations and reduce beam loss.

R8: Investigate the possibility of implementing beam sharing for the pulsed parts of the J-PARC complex (e.g. RCS and MR) to enable e.g. machine development with a fraction of the beam while delivering beam to the users. Such a system can be developed over time to increase flexibility.

Items for the Next Meeting

The committee would like to hear from the J-PARC accelerator team in particular to

1. Present an inventory list of major accelerator device and sub-systems including the mean-time-between-failure (MTBF), mean-down-time (MDT), and lead-time-for-replacement.
2. Present personnel protection system implementation and practice including access control system, radiation safety program, and general personnel hazard analysis and mitigations.
3. Present the status of the effort to proactively and comprehensively review the MPS system. Also present the decision on the implementation of a new run permit system.
4. Present existing MR collimation system and improvement design.

02 J-PARC Accelerator Overview (BZ, JT)

Findings

JFY2018 has been a year of consistent operations for J-PARC. All three major user areas received highly available beam for users during scheduled beamtime. Beam to the MLF was still limited by target capability. The future of higher-power for each user area was better secured through several achievements in the accelerators and settlement of upgrade plans. The Linac operated consistently for the year, increasing its operation current to 50 mA with studies at 60 mA, including 3-month operation without an ion source change. 1 MW was delivered to the MLF for one full hour with significantly reduced losses. Consistency and availability were good during running periods, and no major failures were suffered. While providing consistent beam, J-PARC has been developing upgrades to all their machines that will lead to significant improvements over the next several years.

RCS for MLF:

- The RCS has provided 400-500 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 1-3 years.
    - 3554 hours of beam delivery were achieved out of 3771 scheduled for the MLF in JFY2018 to Feb 26. The downtime remained very low, achieving an availability of 94.2%, well exceeding the goal of 90%.
    - 1 MW beam is available, but awaits a higher-power target.
    - For the near term, operation will be limited to 500 kW until summer, when a target capable of 500-1000 kW will be installed. Progress towards higher power will depend upon measurements of erosion in used targets.
- 1 MW equivalent beam operation was further affirmed during the past year.
    - Studies continue to demonstrate that 1 MW is available for the MLF. Losses have been again reduced substantially.
    - A 1 MW test of the RCS using the MLF target was performed for one hour. The systems and target behaved as expected, further proving 1 MW capability.
- Long-range plans for 1.2, 1.5, and possibly 2 MW have been studied. J-PARC now understands the scale of work required for these options.

MR with fast extraction for neutrinos:

- Beam power increased slightly to 500 kW in JFY2018. Further beam power improvements will be possible with replacement of the MR magnet power supplies (by JFY2021) to allow a shorter cycle time and then other enhancements to the machine allowing higher beam intensity. Operating hours were limited due to sharing with the Hadron Facility and limited schedules.
    - Beam power to T2K increased from 480 kW to near 500 kW.

    - 1053 hours of beam were delivered out of 1224 assigned hours in JFY2018 to Feb 26, for an availability of 86%, near the 90% goal.
- J-PARC has settled 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 in the mid-term, and the Committee continues to support it.
    - Buildings have been constructed for the power supplies.
    - J-PARC now plans to complete procurement of the power supplies over the next two years and install them in a full-year MR shutdown in JFY2021.
    - With the present schedule, the power supply upgrade will be available in JFY2022. The upgrade implementation has pressured funding of operations, and further funding issues could affect operating run-time in JFY2019 and JFY2020, or delay restart of beam.
- A further 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 plans are now well understood. The mid-term plan has been updated with a gradual rise to 1.3 MW in JFY2028. The Committee is supportive of this program and encourages J-PARC to continue these upgrades after ensuring the timely completion of the power supply upgrades.

MR with slow extraction to the Hadron Facility:

- Beam of up to 51 kW was delivered to the Hadron Facility in JFY2018. Further improvements are planned towards >80 kW with targets in future years.
    - 725 hours of beam were delivered out of 877 scheduled, for an availability of 82.7%, nearing the J-PARC goal of 90% availability.
    - The mid-term plan quotes a goal of 50 kW through JFY2019, 70 kW in JFY2020, and >80 kW in JFY2022.

J-PARC plans to operate the MLF for 170 days in JFY2019, though funding for more days has been requested from the funding agencies. MLF operation will be suspended for a special holiday season in May, but J-PARC will perform beam tuning and studies during that time. The MR will operate for 82 days before the summer, mostly for fast extraction. Running the MR after the summer shutdown is contingent on funding, but the management is hopeful that substantial run time will be added. Seven days are reserved in March 2020 for possible user operations if outages cause beamtime losses earlier in the year.

Comments

Actual hours to the Neutrino and Hadron user areas continue to be challenged by several factors. Funding has limited the time available to operate. Startup and tuning continue to consume a large fraction of the time. This year, there was also a three-month suspension of MR running after the summer shutdown while maintenance was carried out at the Hadron Facility and at Kamioka. This may have been a missed opportunity to coordinate schedules. Finally, there was 10 days of beamtime lost to all users due to an atypical transportation of a spent target.

Downtime due to machine trouble/trips was quantified, and there was no single system that dominated. In fact, there were about 16 subsystems each with > 12 hours of downtime. The numbers were compared to the previous year and there is no clear correlation.

J-PARC responded to the 2018 ATAC Recommendation 1 to explore reductions of time spent on startup and tuning. Planned startup calendars show progress in reducing the number of days for startup. For example, Linac used 4.5 days in 2017, which was reduced to 3 days in 2018, but had to add 2 days for loss mitigation. There is a list of proposed improvements that could yield gains. One particular limitation is the 0-degree beam dump, limited to 600 W and therefore limiting linac studies. Clearly, J-PARC has placed urgency on constraining startup and studies, but it is also clear that these periods are needed to maintain and upgrade performance. There may still be alternatives that allow J-PARC to upgrade their systems to allow studies in the background of their machine operation.

J-PARC responded to the 2018 ATAC Recommendation 2 to implement MR magnet power supply upgrade expeditiously. J-PARC now has a credible schedule to implement the power supply upgrade by JFY2021. Manufacturing is underway and the power supplies will be installed in a year-long shutdown in JFY2021. This plan is pressured by finances, and operations may suffer in the short-term to implement the upgrade.

J-PARC responded to the 2018 ATAC Recommendation 3 to pursue greater allocation of user hours. J-PARC noted that run-time has been limited by funding and that eventual higher-power operation will continue to require studies. Reducing maintenance days is not favored as an approach as these days are useful for both the accelerator and the user facilities. For the MLF particularly users prefer beam to remain consistent with the schedule, while MR users prefer maximal statistics.

The committee recognized that machine development is vital and that maintenance days are required. However, the MR sum of 2101 hours scheduled out of 5017 calendar hours in JFY2018 is low compared to other facilities, especially when no significant upgrades are being performed. Also, there occurred the above-mentioned beam suspension when maintenance was simultaneous at Kamioka and the Hadron Facility. Further gains are possible for the MLF, and especially the MR users.

Recommendations

R4: Seek to maximize operating periods at both the MLF and MR, and maximize allocated user hours within those periods by measures including coordinating the down time requests for different areas of the facility.

03 Status of Linac (ML, TS)

Findings

The reliable operation of the linac at nominal parameters is very impressive and demonstrates a good design, engineering and management. The Linac has since the summer been operated at the nominal of 50 mA successfully. A shorter study with 60 mA was successfully performed which identified several issues to be addressed. The main sources of unscheduled beam stops have been sparks in the RFQ and the beam loss monitors. In addition to this, failures of a 324 MHz klystron and the ion source contributed to down-time. However, it should be stressed that ion source had operated continuously for 2201 hours with at least 47 mA with stable beam at 72 mA delivered for a beam study for higher linac beam power. The RFQ vacuum has been improved and LLRF systems has been modified which has resulted in possible lowering of the trip rate. A new procedure to restart the RFQ after a trip has been tested and reduces the re-start time significantly. The DTL/SDTL multipactor problem has been resolved with cleaning of the tanks (one still to be re-done). The deterioration of the scrapers by beam interaction has been studied, new carbon nano-tubes put into use for wire scanners. A human error made a high-power beam to be extracted to a beam dump foreseen for lower power beam and this drilled a hole in a window. A postmortem was performed and interlocks added. Many linac klystrons are approaching their maximum life time with 8 klystrons in the DTL/SDTL having more than 60, 000 hours of running time; as mentioned before, one 324 MHz klystron failed this year.

Comments

- The possible failure during a run of aging components in the linac and the linac equipment halls such as klystrons (and the supply of spares) is a real concern and must be addressed. It is impressive for team constructing an equipment to demonstrate long running periods but unscheduled beam stops can be a big blow to users who are hit. Preventive replacement of aging components and regular measurements of indicators of failures including non-destructive monitoring of mechanical components permits scheduled replacement of components at a late stage which saves budget and users time. Priorities for the purchase of spares should be strategically planned based on e.g. risk for single point failure, known life time of components and long lead time items.
- The human error of sending a high intensity beam to a dump foreseen for lower power beams is a concern and high-lights the need to review the MPS system. The protection of each individual system seems to be carefully studied and implemented but the interaction of the systems with each other must be better understood. Analyses of hazards for the interaction of systems needs to performed and the correct threshold for action set. An overambitious approach can easily increase downtime due to false beam trips while a too lax approach will risk the damage of equipment.
- The recommendation from the 2018 ATAC to *(2018 R4:) Develop and install an automatic restart procedure for the RFQ sparks* has successfully been addressed and tested. It still needs to be implemented in operations

Recommendations

R1: Establish a robust and uniform prioritization process and develop preventive maintenance plans for dealing with deterioration of equipment and utility infrastructure in all areas of the J-PARC accelerators, taking particular note of equipment of single-point failure, systems that may become obsolete, and devices of long lead-time replacement.

R2: Continue the effort to proactively and comprehensively review the machine protection system to locate hardware systems that are not adequately protected. Implement an MPS review process for all new hardware that is consistent throughout the J-PARC organization. Include analyses of how individual systems can interact with each other in ways that create unsafe conditions.

04 Beam Study Results of Linac (ML, TS)

Findings

Many beam studies have been performed in the last year and the results are impressive given the limited dedicated time available. The studies have focused on remaining issues in the Linac such as the misfiring BLM, momentum stability within and between bunches, Intra Beam Stripping and other sources for beam loss. The Linac has been running since the summer stable at 50 mA and the beam study team has now tested 50 mA at 600 microseconds and 60 mA at operation with 500 microsecond pulses. The main concern is the RFQ power level which is very close to the maximum limit. Due to the earlier reported misfiring of BLMs they have now been modified which has reduced the number of misfires from 15-20 a day to a few a day. The beam loss patterns have been studied and a study with a modified optics to reduce Intra Beam Stripping was successfully performed with significant improvements. The reduction of the bunch-to-bunch momentum spread using debuncher one and two has been done and demonstrates clear improvements in the momentum stability. The momentum stability within the bunch has also been studied and work with new feed-forward algorithms and new LLRF hardware is being done.

Comments

- The high-power beam study shows that the power level in the RFQ tank is close to the limit. The high power is also likely to cause a higher spark rate for a system which already is a dominating contributor to un-scheduled shutdown. A new RFQ is a system with a long lead time and it is wise to start the design of such an RFQ early.
- The algorithm and the tests with new LLRF hardware are good examples of improvements which can be done without radiation exposure and for relatively low cost and should be continued.
- As J-PARC advanced to very high power the need to reduce any avoidable beam loss during standard operation will become increasingly important so it is very important to continue the beam loss pattern and understand (and correct) the reason for beam loss.
- The ATAC 2018 recommendation to *(2018 R5:) Replace the faulty BLM without delay* has been addressed. The modified BLM system now functions as expected with a significant reduction of the number of misfires.

Recommendations

None:

05 Status of RCS (JT, SW)

Findings

The RCS has continued in stable user operation, delivering 400–500 kW beam to the MLF, ~500 kW for MR-FX and ~50 kW for MR-SX. Availability for the RCS only has been very good, at ~99%. Residual doses have been maintained at an acceptable level.

Stripping foil production has been relocated to J-PARC following the retirement of the KEK expert. New HBC foils can now be fabricated at the Tokai site and one of these foils has been used in the RCS.

Deterioration has been seen in a number of pieces of equipment, including discharge damage to two PFN cables, oil leakage in transformers and capacitor banks, a rusted cooling fan in an RF power supply system and failed oil pumps for the choke transformer. J-PARC is preparing a strategy for expendables and spares to achieve reliable operation.

Worker dose rates for the summer maintenance work have been well managed.

A successful high-power trial at 1 MW for 1-hour continuous operation was held immediately before the summer shutdown. There was no significant increase in activation after the 1 MW operation and the target itself behaved as expected, but some issues for improvement were uncovered.

Trials beyond 1 MW were carried out. The results indicated that the RCS has enough capability to accelerate 1.2 MW beam, provided the RF system is reinforced.

Comments

The committee congratulates the RCS team on another year of stable user operations, with excellent availability. Trials at 1 MW and beyond are very encouraging.

The committee supports the efforts of the J-PARC team to produce viable foils at the Tokai site after many years of this work being done at KEK. However, the team is advised to explore the possibilities of foils being produced commercially, as this may prove to be more cost effective in the longer term.

It is now about 10 years since the start of operation of J-PARC and deterioration is becoming evident in components of the RCS (and Linac and MR). It is of concern that there appears to be a lack of spare components or spare cables in some areas. The committee also notes that leaking oil-cooled transformers have a habit of catching fire, which can be almost impossible to put out, and could easily lead to enormous property loss and risk to personnel.

As the J-PARC budget is limited there will inevitably have to be an initiative to prioritize deterioration projects in a quantitative and defensible manner, which may have to bear the scrutiny of government inspectors.

As the facility becomes older a substantial amount will need to be spent on sustainability; for instance, the ISIS accelerator sustainability budget is ~$8M/year (for a much smaller, although admittedly older facility). J-PARC will have to support this sustainability programme and allocate an appropriate budget, simultaneously with the new beam power upgrade.

Recommendations

R1: Establish a robust and uniform prioritization process and develop preventive maintenance plans for dealing with deterioration of equipment and utility infrastructure in all areas of the J-PARC accelerators, taking particular note of equipment of single-point failure, systems that may become obsolete, and devices of long lead-time replacement.

06 Beam Study Results of RCS (SW, SG)

Findings

Great progresses have been made in the past year. By the detailed and comprehensive beam study, with the injection peak current to 40~50 mA, the beam power reached the design goal of 1MW, and 1MW test operation was successfully performed for an hour with well controlled beam loss. By realizing the pulse by pulse switching of tunes, painting, and etc, the beam can meet the different requirements for high power operation of MLF and MR. Much higher beam intensity was tested for achieving beam power above 1 MW, and successfully reach the equivalent beam power of 1.1 MW, and equivalent beam intensity of 1.2 MW.

Comments

- In general, the dynamic aperture (DA) of this kind of synchrotron is large enough, and should not induce beam loss by the limit of DA. It will be helpful to further study the DA, and distinguish the effect of DA and space charge effect.
- It is interesting that the optimized tune for different painting emittance is different. It will be helpful to investigate the reason why for the small emittance beam the tune on the coupling line is good, while for the large emittance beam the same tune induce beam loss.
- The study on sextupole components effects of chicane bump surprisingly strong. We encourage the team to perform further simulations and beam studies.
- An additional family of sextupoles can be considered for compensating the sextupole components of the chicane bump, while the sextupole components induce serious beam loss.
- Before the target can accept beam power of 1 MW, the 500 kW operation with single bunch can well simulate the condition of 1 MW operation for accelerators. This can prove the capability of long-time operation of 1 MW.
- Time for beam studies seems to be very limited and that is slowing progress. With the drive for higher intensities it will be essential to perform more beam studies to assure stable operations and reduce beam loss. Facilities like CERN has solved this problem with beam sharing with an automatic pulse-to-pulse control system which permits a fraction of the beam to be used for machine studies while delivering the main part of the beam to different users.

Recommendations

R8: Investigate the possibility of implementing beam sharing for the pulsed parts of the J-PARC complex (e.g. RCS and MR) to enable e.g. machine development with a fraction of the beam while delivering beam to the users. Such a system can be developed over time to increase flexibility.

07 Status of MR (WF, BZ)

Findings

The MR supplied 485 kW in FX mode (750 kW design) and demonstrated 500 kW over 50 shots with 700 W of beam loss. 520 kW was demonstrated in a single shot. To reach the design power of 750 kW the repetition time needs to be reduced from 2.48 s to 1.3 s, with a later reduction to 1.2 s. The MR supplied 51 kW in stable SX mode (100 kW design) with 51% duty factor and 99.49% efficiency. The SX power is presently limited by the HD Au target. The availability in CY2018 reached 86.9% for FX, 87.7% for SX and 87.3% for the FX+SX.

MR failures are dominated by cooling water flow problems for the quadrupole and bending magnets, RF and the extraction system. In case of a failure the tunnel can be accesses after 4 h wait time in order for the residual activation to decay. Some oil leaks were caused by corrosion due to seawater exposure.

Three new power supply buildings are already complete. One of the new fast ramping power supplies was tested with the actual load of 16 bending magnets, and the design current for the up-ramp, flattop and down-ramp were demonstrated. A second and third new PS were installed in JFY2018. Also tested were a second harmonic cavity.

Comments

Both the FX and SX beam power has been increase steadily over the previous years. The demonstrated availability is close to 90%, which is a reasonable target number. Some preventive maintenance items are delayed due to budget constraints, increasing the risk to operations and possibly preventing the reach of the 90% availability goal.

The cooling water failures are detected through reduced water flow, but the root cause of the reduced flow has not been determined yet. The new PS has demonstrated the main current, but the ripple was not yet measured for the planned operating cycles. A large ripple could lead to beam losses early in the energy ramp and limit the SX performance.

Recommendations

R1: Establish a robust and uniform prioritization process and develop preventive maintenance plans for dealing with deterioration of equipment and utility infrastructure in all areas of the J-PARC accelerators, taking particular note of equipment of single-point failure, systems that may become obsolete, and devices of long lead-time replacement.

08 Beam Study Results of MR (SG, WF)

Findings

Stable operation has been realized for 490 kW beam power, with losses of about 500 W. 500 kW operation for a series of 50 shots was done successfully with 700 W loss.

The losses are localized at the collimation system, with 50 W lost in the transfer line with the RCS and 480 W lost in the ring. Both collimation systems are designed to cope with 2 kW.

A new working point has been chosen to increase the tunability with respect to higher intensities, accompanied by the compensation of some resonances with the available sextupoles.

Losses are generated by: a) beam quality from the RCS; b) mechanical aperture restrictions; c) transverse resonances; d) transverse instability from resistive wall.

The tune shift measured during the injection process was corrected for the eight bunches with a new tune tracking compensation, reducing the losses for the run to 450 kW from 850 W to 590 W.

The radiation protection survey showed that the hot spots correspond well to the points where losses are expected, e.g. at the collimation system and the injection.

Longitudinal coupled bunch instabilities appear for operation at about 500 kW. In addition, the current of the anodes lacks margin (about 10%) to be able to significantly increase the power. The instabilities are to be damped by a spare cavity used as longitudinal damper. Dipolar mode 8 is the dominant one.

During a 520 kW test with a magnetic cycle of 2.48 s the losses were 2%. This result is encouraging for the potential operation for example at 1.1 MW with a cycle 1.16 s long, although the losses doubled compared to the operation at 490 kW. These losses are probably excessive and linked to the fact that the machine settings of 490 kW were used for the test, so not optimized. The same is for a test done with two bunches accelerated to have 143 kW (570 kW equivalent). In this case the losses would be 3%.

The current plan is to increase the power to 500 kW in the 2.48 s cycle for FX, and to have a stable operation already this spring. Further power increase to 750 kW requires the new main dipole power supply that should be deployed in 2021.

Comments

It seems that the machine time available for studies has been reduced to a minimum compatible with the optimization of the users' time. The concern remains that time has been reduced to a bare minimum. The committee recognizes the difficulty encountered in optimizing the time available for users and for the setting up of the machine and for studies.

The assumption that beam losses increase linearly with beam power should be motivated by further studies (simulations and experiments), to better justify functional specifications for the design of the future collimation system.

The functioning LLRF system should be look at carefully, especially for transient beam loading compensation. This feedback, in fact, could excite these modes if not perfectly adjusted, and could, with the impedance of the cavities, be the source of the observed coupled bunch instabilities. For higher beam intensities, it should be studied if quadrupole modes appear in addition to dipole modes.

Recommendations

R6: Improve the understanding of MR longitudinal instabilities observed at powers above 450 kW, with the ultimate aim of implementing an active feedback system either on the cavities themselves or as longitudinal damper.

09 Status of SX (WF, SG)

Findings

The SX Runs 79 (with Linac pulse current of 40 mA and pulse width 300 μs) and Run 81 (50 mA and 100 μs) both delivered 50-51 kW power, while the SX power is presently limited by the target.

Beam losses at the Electrostatic Septum (ESS) can be reduced by increasing the resonant sextupole strength. A transverse instability can be observed during debunching, which can be be mitigated for current intensities by injecting with an RF phase offset in order to increase the momentum spread. In the future a VHF cavity will be used for longitudinal emittance blow-up.

Mitigation of the instability is considered the most important part in raising SX power in the future, when the HD target is upgraded.

SX for COMET (COherent Muon to Electron Transition) requires an extinction ratio for $< 10^{-9}$. An insufficient extinction after the 4th bunch was observed, which could be cured by a 600 ns adjustment of the injection kicker timing.

Test for further intensity increases are also limited by the available time for beam studies.

Comments

The HD target is being upgraded to 90 kW in the present year. With the completion of the target upgrade up to 70 kW of SX power is expected before the MR PS upgrade.

Presently the instability during debunching is considered the likely limit for the SX operation. To cure the instability other means of increasing the momentum spread can be used (e.g. phase jump to unstable fixed point before debunching).

Recommendations

None.

10 Cabling and Grounding of J-PARC (JT, BZ)

Findings

J-PARC responded to 2018 ATAC recommendation (2018 *R9): Document the policy on grounding and electromagnetic compatibility (noise avoidance) and have personnel trained in this policy.*

The policy on grounding and noise avoidance was originally produced during a series of task force meetings held during 2003. This policy was followed when installing equipment during the construction period, with some further review of the rules after the introduction of additional noise countermeasures which were required as the noise environment changed.

Subsequent specific noise problems have been understood and rectified, and new component installations undergo several reviews. Particularly noted was multi-point grounding of high-voltage systems.

All the policy documentation still exists and has now been organized in a browsing system so that it can be easily accessed.

Personnel training in the grounding policy is being addressed by holding seminars with about 20 staff having been trained so far.

Comments

The J-PARC team should video the next seminar on grounding policy and make it available as an on-line training resource. This could become a mandatory part of training, requiring sign-off by line management.

Recommendations

None.

11 MPS Issues (MP, ML)

Findings

- An effort has begun to proactively and comprehensively review the MPS system to locate hardware systems that are not adequately protected.
- The STAMP method has been selected to systematically identify the weak points.
- The task of reviewing the MPS system is still in the early stages.
- New equipment is reviewed by various committees prior to installation, however the rigor of the MPS review varies from case to case, and there are no standard MPS review requirements.
- There has been another MPS-related occurrence in Oct. 2018 with the hole burned in the L3BT vacuum window.

Comments

- As the beam power is increased the consequences of the weak points in the MPS system are also increased.
- Recent examples include the MR vacuum leak in February 2016 caused by the extraction septum magnet, the unintended beam delivery to the MLF in January 2018 due to the failure of a pulsed power supply to energize a deflection magnet, and the hole burned in the L3BT vacuum window in October 2018 due to human error in sending high power beam to a lower power dump.
- The ATAC2019 committee recognizes that the task of proactively and comprehensively reviewing the MPS system is a large one that will require significant manpower.
- However, the committee also believes that this effort is important and will ultimately benefit the J-PARC facility, especially as the beam power is increased and the MPS weak points cause increasingly severe consequences.
- The STAMP method presented by Yamamoto-san appears to be a reasonable approach to addressing this issue.

Recommendations

R2: Continue the effort to proactively and comprehensively review the machine protection system to locate hardware systems that are not adequately protected. Implement an MPS review process for all new hardware that is consistent throughout the J-PARC organization. Include analyses of how individual systems can interact with each other in ways that create unsafe conditions.

12 Towards 1.3 MW Operation (SG, WF)

Findings

The upgrade to 1.3 MW beam power for the FX involves a first step, the operation at 750 kW. The 750 kW requires an upgrade of the main dipole power supply to reduce the length of the magnetic cycle from 2.48 s to 1.3 s. The subsequent reduction of the cycle length to 1.16 s and the increase in intensity to 3.3 10^{14} ppp would allow to reach 1.3 MW.

Three systems need to be improved to allow for increased power: the main dipole power supply, the collimating system, part of the injection and extraction hardware and the RF system.

A module of the new main dipole power supply has already been tested with 16 main magnets, with very encouraging results for 1.3 s long cycles. The energy recovery system works as expected, even if no measurement of noise has been presented on the magnetic field. The presence of noise could have an effect on the beam during the start of acceleration and slow extraction. Cycling tests at 1.16 s will be done during the summer, with the idea of comparing the results with electrical simulations of the system.

As for the RF system, currently 7 cavities are installed in the MR, 6 used on the fundamental harmonics and 1 used on the second harmonics. It is planned to increase the number of cavities to 9 for the fundamental harmonics and to 2 for the second harmonics for the operation at 1.32 s in 2022. For the operation at 1.16 s, instead, 11 cavities are foreseen for the fundamental frequency. 4-gaps cavities are preferred over 5-gaps cavities to reduce the anode current, which will however have to increase with the increase in beam intensity, and therefore the power.

The injection kicker will have a new matching box to reduce the risk that the service temperature rises above 150 degrees in operation and damage. The mechanical aperture of the extraction septa such as that of some quadrupoles will be increased to reduce the losses during the fast extraction.

The number of collimators will have to increase in order to absorb a maximum of 3.5 kW instead of the current 2 kW.

The external beam dump can now receive only 20 shots per hour, and is not adequate for the increase in power or even for the setting up of future beams. A conceptual study exists for a new dump.

Larger beam intensity means also more losses: 519 kW tests have generated about 1 kW of losses, implying that for the 1.1 MW operation about 2 kW of losses can be expected. The new collimation system should be able to cope with that. Optimisation of the working point led to some reduction in losses, but not sufficient to avoid the upgrade of the collimation system.

To reach 1.3 MW by 2028, the priorities are: upgrading the main dipole power supply to reduce the length of the magnetic cycle, implementing the new collimation system, upgrading the injection and extraction hardware and lastly, in terms of time, upgrading the RF system.

Comments

The upgrade of the collimation system requires an in-depth analysis before the final implementation is realized, since it is not yet clear the willingness to implement a single or double stage system.

Before using the new power converters of the main dipoles for the whole machine it would be advisable to have extended tests, possibly with a circulating beam, with the modules already available in order to intercept possible problems before the final deployment scheduled for 2021.

The two transverse damper systems look promising in fighting a transverse instability observed during acceleration. It is not clear, however, the reason why two systems are needed and not just one is sufficient as the fact that there was no reduction of the beam losses. A better understanding of instability as well as the mechanism that reduces it would be desirable.

Recommendations

R5: Strengthen verification of acceptance criteria specifications and documentations on major subsystems; for example, specify and measure the new MR power supply ripple throughout the planned operating cycles.

13a Upgrade of Linac and RCS (Linac) (TS, ML)

Findings

RCS will deliver the beam with 1.2 MW a few years later (1 MW for MLF and 0.2 MW for upgraded MR) and the Linac has to deliver the beam to RCS with the pulse width of 0.6 ms. The Linac and RCS team is steadily pursuing R&D to realize the stable 1.2 MW operation. The MEBT1 upgrade is planned to reduce the beam loss. The Linac and RCS team have a future plan to increase the beam power up to 1.5 MW or 2 MW for MLF second target project and ADS project. They also conduct the technical R&D for the future upgrade. The Linac has tested 50 mA with 0.6 ms pulse length and 60 mA with 0.5 ms pulse length. The new high intensity ion source has been developed and the stable operation has been performed with 100 mA for 8 hours.

Comments

- The R&D studies in the Linac and RCS produce the good results but the coherence with MR and MLF upgrading project is not clear. The Committee suggests that the Linac and RCS team should make the R&D and installation schedule, which should be consistent with the MR and MLF upgrade schedule. Upon upgrading, the Linac and RCS team should evaluate quantitatively the merit and the risk (shutdown time, commissioning time, cost and so on) of the modification of the existing accelerator system.
- The improvements in MEBT1 are important to reduce the beam loss. However, the space of MEBT1 is very small and the realistic mechanical design and the installation, commissioning scenario of the new buncher should be made.
- Instead of chopping beam in MEBT1, another option is chopping beam in LEBT. If the LEBT chopper is used, the space in the MEBT1 can be released for additional buncher, and the deposit of high power chopped beam can be avoided in MEBT1. The LEBT chopper now is used in CSNS, with rise time less than 15 ns.
- For > 1.5 MW operation, it is likely that two parallel front-ends are required with H- and H+ ions. As this is a long lead-time modification with high cost, a feasibility study of H+ acceleration could be done now without major modifications. It could yield important information about charge dependent systems up-streams such as correctors.

Recommendations

None.

13b Upgrade of Linac and RCS (RCS) (SW, MP)

Findings

Based on beam commissioning and operations experience, an upgrade scheme has been figured out, and important issues have been identified. The equivalent beam power of 1.1 MW and equivalent beam intensity of 1.2 MW have been achieved, and these results show that, up to 1.2 MW, the space charge effect is acceptable. This is a good base for performing the upgrade.

Comments

- More extensive computer simulations and beam studies can be performed to optimize the specifications for the upgrade, especially for beam powers above 1.5 MW.
- The impedance of the extraction kicker is an important source of instability, and efforts have been made to reduce the impedance. We encourage the J-PARC accelerator team to re-confirm the threshold of other types of instabilities for high power upgrades. For reference, the CSNS team found that resistive wall instability can be an issue for high power scenarios (NIM-A 728 (2013) 1-5).
- The study of new kicker impedance should be involved in the design and tuning of the new kicker.
- The feasibility to upgrade to 2 MW should be further investigated. The work shown in the presentation is not enough to prove the feasibility of a 2 MW upgrade.
- The waveforms of the present kickers show strong ringing after the rise time, so the new kicker design should consider this problem.

Recommendations

None.

14 RCS Injection Area (MP, BZ, ML)

Findings

- The injection foil area is a high maintenance area. Examples of typical maintenance activities include capacitor repair on ceramic ducts, water cooling repairs, vacuum leak repairs, foil change out etc.
- The present mechanical arrangement does not allow the addition of efficient radiation shielding, so a new design is planned that will more easily accommodate a temporary shielding system.

Comments

It is commendable to minimize radiation dose to workers through engineering solutions such as adding movable shielding around highly activated beam line components. However, in the case of the movable shielding planned for the RCS injection area, the committee is concerned about the cost/benefit analysis. The *cost* will certainly be high (due to extensive redesign of the injection area including new shift bump magnets, the shift bump power supply reconfiguration, radiation dose to workers installing the new beam line components, etc.). However, the *benefit* was not well quantified. For example, what is the expected dose reduction for the various jobs mentioned in the presentation, given that not all the dose comes directly from the stripper foil, and the shielding does not cover the upstream and downstream portions of the stripper foil region? The cost/benefit may be favorable – it's just that it was not evident to the committee based on the information presented. The committee suggests that the case for installing the new shielding design should be reviewed to make sure that the new shielding can be justified.

Recommendations

R7: Make a detailed installation plan for the new RCS injection area shielding design that includes the expected total radiation dose to the installation team.

15 RCS RF Cavity (BZ, JT)

Findings

The RF system of the RCS was studied for the various upgrade plans. Increase of the resonant frequency was found effective to allow performance up to 1.2 MW; beyond that power up to 2 MW could be addressed by a complete replacement of cavities and reconfiguration of the amplifier system. Upgrade of the anode supply was carefully avoided in all cases. A swing in the anode voltage caused by the broad-band amplification and push-pull configuration was found to be an important limiting factor.

The RF system has already been upgraded for 1 MW by augmenting the anode supply with additional inverter units to increase the maximum current. Addition of more units is considered very expensive, and there is little physical room to affect such an upgrade. Accordingly, J-PARC has approached this issue by trying to avoid adding to the existing anode supply.

Detuning the RF cavities has been effectively used by J-PARC as a means to reduce anode current at high beam current. This process works by increasing the resonant frequency of the cavities above the excitation frequency such that the energy dissipation is greater at zero current, but less at high current (where beam loading dominates). This approach can be extended to 1.2 MW operation, depending on the operating margin desired.

J-PARC discovered a new effect of very high anode voltage swings due to the multi-harmonic amplification in the push-pull configuration. Broad-band RF from the harmonic RF and beam-loading compensation and the push-pull configuration causes the anode current to exceed limits for certain phases of the cavities. This effect was found to be quite limiting even with cavity detuning and eliminating the push-pull configuration.

The chosen solution is to change all the cavities to single-ended cavities (no push-pull) with a greater number of gaps (but same number of tubes), and higher impedance cores. This involves replacement of all cavities with the new design, as well as reconfiguration of the amplifiers. With this approach, J-PARC expects it can reach 2 MW capability in the RCS with the existing anode power supply.

Comments

This plan for replacement is still new and the timeline is not entirely clear, nor the priority with regard to other upgrades. The higher impedance cores have been used in the MR, but this particular cavity design is new, and has not been prototyped. At this level of detail, the plan appears to be effective to reach 2 MW, but unfortunately requires all new cavities and significant reconfiguration of the amplifiers.

Final design and prototyping of the cavities are still outstanding. Replacement of the cavities is expected to occur at a rate of three per year for a total of twelve cavities. This plan is then likely to take at least four years to implement after development, and may be lower priority than other upgrade efforts in the RCS. Significantly higher heat dissipation must additionally be managed.

The Committee notes that the proposed cavities have a greater number of gaps than the existing cavities and use a higher impedance core material. The longitudinal dynamics of these additional impedances should be considered in plans to go to higher intensity.

Recommendations

None.

Homework 1: Present 5-year profile of projected beam power / availability / user hours ramp-up goals for MLF, FX, and SX, respectively, identifying focused areas of improvements on an annual basis (JT, BZ)

Findings

In the short term the intention is to ramp the MLF beam power from 600 kW to 1MW, with step-by-step increases dependent upon maintaining reliable beam operation and target health. The expectation is that 1 MW operation will be achieved within ~2 – 3 years. Year-on-year system improvements to facilitate these increases in beam power have been described in detail in other sections. The goal is to realise availability >90% at all power levels.

For each JFY a request to the government for 9 cycles will be made, but the current expectation is that ~7 – 8 cycles will be granted.

The MR upgrade path and increases in beam current have been described in detail in other sections.

The intention is to realise 90% availability for both FX and SX in JFY2019 and to maintain that level after the long shutdown planned for JFY2021.

After the long shutdown 9 cycles of MR operation will be requested (the same as for the MLF), although funding has consistently provided for fewer cycles.

Comments

It is ambitious to think that MR availability of 90% will be achievable immediately after the major equipment changes planned for the JFY2021 long shutdown.

Clear, year-by-year goals of user time, beam power, and availability will be useful guides for J-PARC staff to plan and prioritize activities.

Recommendations

None.

Homework 2: Describe the current run permit system pertaining to beam destination modes and beam structure modes and coordination over the entire facility (MP, ML)

Findings

The J-PARC control system is well designed to ensure regulatory compliance, which for the beam dumps corresponds to a maximum allowable number of particles per hour. However, the control system does not limit the maximum beam power (i.e. particles per second) delivered to any of the beam destinations. This allows human errors to accidentally cause dangerously high beam powers to be delivered to low-power-limit beam dumps and cause damage to beam-line equipment. One example of this is the hole that was burned in the L3BT beam dump vacuum window in October 2018, due to accidental delivery of high-power beam to the dump.

Comments

- The hole burned in the L3BT dump vacuum window could have been prevented by a run permit system.
- Run permit systems are commonly used at other accelerator facilities to automatically limit the beam pulse length and/or the beam rep rate when the accelerator is lined up for beam delivery to low-power destinations.
- The review committee suggests that J-PARC consider implementing a such a system to reduce the probability of human-error caused equipment damage. A run permit system would become even more valuable to J-PARC as the accelerator reaches for ever-higher beam powers.

Recommendations

R3: Complement the machine protection system with a run permit system pertaining to modes of beam destination and allowed beam structure, duty factor, and beam power setting to minimize potential human errors.

Homework 3: Describe specifications and acceptance criteria for the new MR power supplies (WF, SG)

Findings

The QFR PS has been characterized in terms of current output, ripple at flattop (for SX performance), and long-term operation (> 8 h). A new BM PS has only been partially characterized – the FX waveform has not been tested yet, the current ripple measurement has not yet been done, and neither the long-term operation demonstrated.

Comments

The full characterization of the BM PS should be done as soon as possible. For the new power supplies, the power circuit hardware is provided by a commercial vendor and the controller by KEK. The J-PARC team relies on KEK to resolve any ripple or tracking issues of the new PS with the controller.

Recommendations

R5: Strengthen verification of acceptance criteria specifications and documentations on major subsystems; for example, specify and measure the new MR power supply ripple throughout the planned operating cycles.

Appendix 2 – Agenda

Agenda for A-TAC2019 (Q&A included for each report) 2/28/2019

February 28, Thursday Venue: a conference room on the 2nd floor of theJ-PARC Research Building

Time		Period	Category	Title	Speaker
8:00		*Departing the hotel, "Terrace Inn Katsuta", for J-PARC*			
8:40	9:00	0:20	Time for LAN Connection	*(+20minutes for registration at the JAEA gate)*	
9:00	9:15	0:15	**Executive Session**	*Closed*	
9:15	9:55	0:40	**Project Status**		N. Saito
9:55	10:25	0:30	**Accelerator Overview**	J-PARC accelerator overview	K. Hasegawa
10:25	10:55	0:30	**Coffee break and Group Photo**		
10:55	11:25	0:30	**Status & Commissioning**	Status of Linac	H. Oguri
11:25	11:55	0:30		Beam Study results of Linac	Y. Liu
<< lunch >>		1:05	*Lunch will be served.*		
13:00	13:30	0:30	**Status & Commissioning**	Status of RCS	K. Yamamoto
13:30	14:00	0:30		Beam Study results of RCS	H. Hotchi
14:00	14:30	0:30		Status of MR	F. Naito
14:30	15:00	0:30		Beam Study results of MR	Y. Sato
<< coffee break		0:20			
15:20	15:40	0:20		Status of SX	M. Tomizawa
15:40	16:10	0:30		Cabling and Grounding of J-PARC	M. Yoshii
16:10	16:40	0:30		MPS Issues	N. Yamamoto
16:40	17:20	0:40	**Executive Session**	*Closed*	
<<Reception>> 17:45 - 19:30 at the KEK 1-gou kan					
March 1, Friday					
8:00		*Departing the hotel, "Terrace Inn Katsuta"*			
8:40	9:10	0:30	**Executive Session**	*Closed*	
9:10	9:50	0:40	**MR upgarde**	Toward 1.3MW operation	S. Igarashi
<< coffee break		0:20			
10:10	10:50	0:40	**Li/RCS upgrade**	Upgrade of Li and RCS	M. Kinsho
10:50	11:20	0:30		RCS injection area	J. Kamiya
11:20	11:40	0:20		RCS RF cavity	M. Yamamoto
<< lunch >>		1:00	*Lunch will be served.*		
13:00	14:00	1:00	**Homework Session**		
14:00	17:30	3:30	**Executive Session**	*Closed*	
<< dinner >> 19:00 - 20:30 at the restaurant in Katsuta					
March 2, Saturday					
8:00		*Departing the hotel, "Terrace Inn Katsuta"*			
8:40	10:30	1:50	**Executive Session**	*Closed*	
10:30	11:30	1:00	**Recommendations to J-PARC**		J. Wei/A-TAC committee
adjourn					
			Tour(optional)		