Report from the 8th Meeting of the Accelerator Technical Advisory Committee for the Japan Proton Accelerator Research Complex (J-PARC)

March 5-7, 2009
JAEA
Tokai, Japan

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INTRODUCTION, SUMMARY, AND MAJOR RECOMMENDATIONS

The Accelerator Technical Advisory Committee (ATAC) for the J-PARC Project held its eighth meeting over the period March 5-7, 2009 at the JAEA site in Tokai, Japan. The committee heard presentations from project staff on March 5-6, held several closed sessions to discuss reactions and opinions, toured selected areas of the facility, and presented a verbal report to project management on March 7. This report was subsequently presented to the Meeting of the International Advisory Committee (IAC) on March 9.

ATAC members in attendance at this meeting included: R. Garoby/CERN, I. Gardner/RAL, S. Holmes/Fermilab (chair), A. Noda/Kyoto, T. Roser/BNL, L. Young/LANL (retired), and J. Wei/Tsinghua Univ/BNL.

D. Gurd/ORNL (retired) and I. Hoffman/GSI were unable to attend.

The Linac Energy Upgrade Plan was reviewed by a subcommittee of the ATAC on March 4. The committee was chaired by R. Garoby of the ATAC, and reported to the ATAC meeting. Other members of the Energy Upgrade committee included L. Kravchuk/INR, P. Ostroumov/ANL, and T. Shintake/Riken.

The ATAC heard comprehensive presentations covering all aspects of the project. Significant progress has been made over the last year on all fronts: J-PARC construction is now essentially complete and all elements of the complex have seen beam with the exception of the neutrino beamline (scheduled for April startup). Highlights of the last year include:

- Successful commissioning of the MR to 30 GeV in December 2008, including slow spill to Hadron Experimental Hall
- Startup of MLF operations for users in December 2008
- Successful radiation safety inspection of the MR in February 2009

It is worth noting that all of these milestones were achieved on a schedule that was presented to the ATAC three years ago. This is a very significant accomplishment and the ATAC offers congratulations to the entire J-PARC team!

The JFY2009 operations budget has now been established at a level that will support 110 days of operations. This is welcome news and will allow essentially full utilization of the J-PARC complex as it transitions from commissioning to operations. However several significant issues have arisen in the initial commissioning that are challenging the J-PARC management and staff

- RFQ issues are limiting the RCS power to 20 kW,
- Partial failure of MA cores in one of the RCS rf stations has reduced available voltage by 3%, and is worrisome in its broader implications, and
- Excessive ripple on the MR dipole power supply system is limiting cycle time and negatively impacting slow extraction

The 400 MeV Linac Energy Upgrade has received funding of 43 Oku-yen to start construction in JFY2009. This is approximately half of the total required funding to complete the upgrade. This is a most significant development in realizing the full potential of the J-PARC complex.

The ATAC sees the primary challenge at this time as the efficient transition to operations while simultaneously realizing the full potential of the J-PARC complex. Areas requiring high level attention include:

- Maximizing performance of J-PARC over the first several years of operations through coordination of activities aimed at providing maximum delivered beam to users, while simultaneously resolving performance issues,
- Establishment of a sufficient operations budget and staff support for >200 days/year of reliable operation in JFY2010 and beyond, and
- Execution of the linac energy upgrade

Finally, the ATAC wishes to express its appreciation to JAEA and KEK management and support staff for their hospitality during this meeting, and to the J-PARC staff for their comprehensive presentations.

Summary and Major Recommendations

Linac

The linac has been in operation at its design energy of 181 MeV for more than a year. It is operating well with the exception of the RFQ and perhaps the ion source. The system was achieving ~90% reliability prior to the failure of the RFQ.

Comments and Recommendations

- One klystron was ordered and delivered, bringing the spares inventory up to four out of the five desired. The long term expectation is 2 to 3 klystron failures per year. The committee suggests that the implementation of a test/conditioning stand would enhance overall system reliability.

  Recommendation: Bring the spares inventory up to ~5 as soon as possible, and negotiate a long-term agreement with Toshiba to maintain inventory at this level.

- The ion source has performed well, although there have been a few recent problems (filament failures and high voltage discharges).

  Recommendation: Dedicate more manpower to development of Ion Source to improve reliability and to provide 60 mA current capability required for 1 MW operation.

- It is observed that the vacuum in the RFQ increases by an order of magnitude when exposed to the LEBT. The ATAC suspects this is an issue with hydrogen migration, which is not effectively pumped by ion or turbo-molecular pumps. The committee also believes it has been demonstrated that H- is being prematurely stripped due to poor vacuum in the LEBT

  Recommendation: Replace the ion pump and/or TMP with cryopumps.

Recommendation: Improve the vacuum in LEBT, perhaps by increasing length of LEBT vacuum manifold and by adding beam scraping that keep ions that are outside the acceptance of RFQ from being injected into RFQ.

- Serious discharge problems developed in the RFQ during run #18 which was the first high power demonstration run. The cause of the discharge is still unknown, but may have been caused by high partial pressure of hydrogen. Measurement of gas species may help diagnose cause of breakdown. The poor vacuum may be caused by ion pumps being saturated with hydrogen (see prior comment). The committee suggests investigation of the residual gas composition.
- The committee feels that there is potential for further damage to the RFQ if it is continued to operate with frequent breakdowns.

Recommendation: Give investigation of the RFQ highest priority.

Recommendation: Improve the vacuum in present RFQ by replacing existing pumps with cryopumps.

- The J-PARC team is preparing to procure a new RFQ immediately. The lead time is estimated to be approximately 18 months

Recommendation: A new RFQ should be built, but the cause of the breakdown in the existing RFQ should be identified before proceeding. Once the cause of the breakdown is identified the design of the new RFQ should be modified as appropriate.

- Depending upon whether the existing RFQ can be recovered to operate at the full design specification, the ATAC suggests that a new design that can provide 50 mA for 1 MW operation should be considered. The committee suggests not to use pi-mode stabilizing loops (PISLs) for dipole suppression as they maybe causing the discharge problem and evidence indicates they may multipactor. Insufficient cooling coupled with heating from multipacting may also have caused one or more PISLs to distort leading to high voltage break down.

Recommendation: Consider a new design for the backup RFQ, capable of 50 mA. The committee suggests 4 rod stabilizers on end plates similar to those used on LEDA instead of PISLs.

Linac Energy Upgrade Plan

The linac energy upgrade will restore the 400 MeV linac capability that was included in the original scope of Phase 1 of the J-PARC project. The Linac Energy Upgrade Plan was reviewed by a subcommittee of the ATAC the day before the ATAC meeting. Their report is contained in the Linac Energy Upgrade section of this report.

The upgrade includes the construction of 21 acceleration modules, two buncher modules, and two debuncher modules. The modules all utilize (room temperature) annular coupled structures (ACS). To date two buncher modules have been fabricated and tested at high power, and one low beta accelerating module has been fabricated and tested at high power. In addition three prototype 972 MHz klystrons have been tested, with the third satisfying the upgrade specification. A complete conceptual design of the upgraded linac exists. 43 Oku-yen have been made available for construction in JFY2009

Comments and Recommendations

- The ATAC believes that the J-PARC staff has the experience and capabilities to successfully implement the linac energy upgrade, and that initiation of procurement of the majority of accelerator components could begin immediately.

- The committee considers that the official schedule is very tight. Coordination of installation and commissioning planning with facility users needs to take place as soon as possible.

- The linac energy upgrade will not in and of itself increase beam power from the RCS. The beam intensity delivered from the linac will also have to increase.

- The Committee feels the plan to install the ACS linac in phases, first at 300 MeV and then later at 400 MeV, is not the most effective utilization of time and resources.

  Recommendation: The committee recommends that the linac energy upgrade be implemented in a single step.

  Recommendation: The linac energy upgrade should be implemented only after the RCS injection has been upgraded to 400 MeV and the front-end is capable of producing a pulse intensity that supports an increase in RCS output power relative to that achievable with 181 MeV injection energy.

3 GeV Rapid Cycling Synchrotron

Great success has been achieved in beam commissioning in the RCS. RCS operations in support of the MLF were initiated in December. In parallel the RCS is providing beam to support commissioning of the MR. Current operations are limited to 20 kW due to issues with the RFQ. However, the RCS has operated at beam powers above 100 kW for an hour, and with single bunch intensities equivalent to 310 kW. There is an excellent understanding of the optics and beam dynamics within the RCS, and beam loss patterns agree well with simulations. Congratulations are offered to the entire RCS team on these fine accomplishments!

Comments and Recommendations

- Losses observed during the 310 kW single pulse operations corresponds to 180 W of lost beam power, well within the 4 kW limit of the RCS beam collimation system. If this beam loss can indeed be localized to the collimator this would demonstrate the 300 kW beam power capability of the RCS and extrapolation to 600 kW would be plausible.

  Recommendation: Determine the loss distribution in the RCS for high intensity operation and localize losses in the collimators.

- Significant degradation in the shunt impedance of one out of three gaps of rf cavity # 7 was measured starting at about August 2008. The cavity was most recently operated with only two gaps. Inspection found that all six Magnetic Alloy (MA) cores corresponding to this gap show some degree of damage. Based on the damage to cores in cavity #7 it would be prudent to assume that damage is developing in other cavities. There is some preliminary evidence based on the general downward trend of shunt impedances in all cavities.

  Recommendation: At the earliest opportunity inspect cores of gaps that presently don't show impedance degradation and verify that there are no signs of damage.

  Recommendation: Prepare a spare RCS rf cavity with new cores that can be used in the future to replace a failing cavity in the ring.

  Recommendation: Continue to pursue alternative fabrication techniques.

- The committee believes the RCS has an inherent capability of operating at 300 kW once issues in the RFQ are resolved.

Main Ring Synchrotron

MR installation is complete and beam commissioning is well underway. Beam has been accelerated to 30 GeV and resonantly extracted. Beam commissioning is adhering to the schedule established three years ago. Most issues associated with pulsed devices identified last year have been resolved. There is excellent understanding of the machine optics and nearly 100% beam efficiency has been achieved at an intensity of $4{\times}10^{11}$/bunch (1% of full intensity). Congratulations are offered to the commissioning team on these exceptional achievements!

Comments and Recommendations

- Excessive current ripple has been observed on the dipole and quadrupole power supplies during initial startup. Associated issues have limited the cycle time to 6 seconds, and are impacting the quality/efficiency of the slow spill. Modifications to the supplies have reduced the ripple substantially, to the point that the ATAC believes there should be no impediment to fast extraction for the neutrino program.

- Slow extraction has been successfully achieved with reasonable efficiency at 30 GeV, but with poor spill quality due to power supply issues.

  Recommendation: Consider a dedicated low voltage supply for regulating current at flattop

- Intensities and cycle times required to support neutrino operations are yet to be demonstrated. The stated goal for the neutrino program is to deliver 100 kW for 1×10^7 seconds in the year following the summer 2009 shutdown. The ATAC believes that a goal of achieving 100 kW in JFY2009 is achievable, but that operating at this level for 1×10^7 seconds by the summer of 2010 will be extremely challenging.

- 100 kW requires operation of the RCS at a 300 kW instantaneous rate accompanied by a 3.6 second MR cycle time. This will require resolution of both the RFQ and the MR dipole power supply issues. It will also require installation and commissioning of the 5th rf station. It is also noted that beam intensities in the MR have been limited to ~1% of that required for 100 kW operations

  Recommendation: The commissioning team should move toward commissioning with high intensity (100 kW equivalent) single beam transfers from the RCS to the MR as soon as possible.

  Recommendation: The MR team should start considering possible stacking mechanisms in the MR that could raise beam intensity beyond three times the RCS beam intensity

- Given the observations of core degradation in the RCS, the cores in the MR cavities deserve careful monitoring.

  Recommendation: Prepare an additional MR rf cavity, bringing the total number to 6.

  Recommendation: Continue to pursue alternative fabrication techniques.

- The committee has a concern that it was stated that spares do not exist for essential MR components.

- The committee believes the MR has an inherent capability of operating at 100 kW once issues in the RFQ and dipole power supply are resolved, and the 5th rf station is commissioned.

Commissioning/ Operations/Power Projections

The J-PARC Phase 1 construction project is officially completed at the end of JFY2008 (March 31, 2009). Significant progress has been made in beam commissioning and in meeting previously established milestones as detailed above. The JFY2009 operations budget has been secured at a level sufficient to support 110 days of operations.

Comments and Recommendations

- An increase in the operating budget for JFY2010 will be required to support full utilization of the J-PARC complex. The ATAC believes the 110 days of operations supported in JFY2009 is appropriate during the commissioning/operations startup period. However, the committee believes that full utilization of the J-PARC complex would require support for 200 days of operation starting in JFY2010.
- Spares remains an outstanding issue affecting commissioning progress and operating costs. Analysis was presented on the linac klystron systems and on RCS RF cavity cores. The effort needs to be expanded to other systems of the facility where spares are needed. As recommended at prior reviews, a formal document containing performance risks, mean-time-between-failure, procurement lead time, and cost of all major components can be important both in the planning and in communicating with the funding agencies.

  Recommendation: Establish a spares strategy based on a risk analysis incorporating mean time between failure (MTBF), performance impacts of failures, fabrication/procurement lead times, costs, etc. Such a strategy should be used as a basis for establishing the spares component of the operations budget.
- With approval of an aggressive schedule for the linac upgrade, the transition to operations is closely linked to the linac energy upgrade plan. Projections of beam power for the user community need to take into account the actual execution plan of the linac energy upgrade and the mitigation plan of exposed problems uncovered in the early commissioning phase.
- The coordinator for accelerator commissioning needs to lead the effort in developing an integrated plan for transition towards operation. The curves presented showing anticipated peak power delivered from the RCS over the next six years provide a useful tool in providing a context for organizing efforts aimed at improving performance and communicating expectations to the user community. This presentation would be enhanced by providing the projected MW-hours available over the next several years.

  Recommendation: Integrated beam power projections over the next several years should be developed for the RCS and MR.

  Recommendation: The integrated commissioning/operations plan should be extended through the first few years of operations and should be discussed with, and made available to, the user community. The published plan should include estimates of performance, anticipated reliabilities, and the time allocation between users and accelerator physics.

  Recommendation: Develop a roadmap to maximize the potential of the accelerator complex, in support of the goals for long range performance improvements.

LINAC STATUS

- Except for the RFQ and perhaps Ion Source, the linac is operating well.
- Spares: One klystron was ordered and delivered bringing the spares inventory up to four out of the 5 desired. Long term expectation is 2 to 3 klystron failures per year.
  - **Recommendation: Bring the spares inventory up to ~5 as soon as possible, and negotiate a long-term agreement with Toshiba to maintain inventory at this level.**
- Ion source: Performs well but recently problems have developed.
  - During run #17 filament failed.
  - Frequency of high voltage discharge at insulator increased after run #19. If Ion pump is used on LEBT it could have saturated with Hydrogen, but it was reported that Turbo molecular pumps are used on LEBT. In that case, the TMP may not have a fast enough pumping speed for Hydrogen.
  - Ion Source development slowed by man power dedicated to operation and maintenance.
  - Stage #1 full specifications of 36 mA and 500μs pulse length still not demonstrated.
  - **Recommendation: Dedicate more man power to development of Ion Source to improve reliability and to provide 60 mA current capability required for 1 MW operation.**
- LEBT: Vacuum in LEBT causes order of magnitude increase in RFQ vacuum.
  - Ion pumps will saturate with hydrogen after short period of time pumping hydrogen at pressures above $1x10^{-7}$ torr or $1.33x10^{-5}$ Pa and TMP may not have a fast enough pumping speed. Most gases are heavy enough to be well pumped but it is difficult to pump hydrogen efficiently with a TMP.
  - **Recommendation: Replace the ion pump and/or TMP with cryopumps.**
  - The poor vacuum may contribute to RFQ breakdown problems.
  - Vacuum maybe too high in LEBT leading to stripping of H^- ions to protons. This stripping may occur in LEBT and/or RFQ. These protons would then be captured by the RFQ and accelerated causing beam loss at higher energy.
  - The LEBT has a very short pumping manifold between the beam pipe from Ion Source and beam pipe to RFQ. It is likely that gas streaming out of the Ion Source beam pipe moves across manifold like a Jet resulting in very poor vacuum in beam pipe leading to RFQ. This is a possible explanation for the order of magnitude increase in RFQ pressure when gate valve to RFQ is opened.
  - **Recommendation: Improve vacuum in LEBT, perhaps by increasing length of LEBT vacuum manifold. Also adding beam scraping that would help to break up gas jet from Ion source. The beam scraping should be designed to make sure that those ions that are outside the acceptance of RFQ are not injected into RFQ.**
- RFQ: Serious discharge problems developed during run #18 which was high power demonstration run. Cause of the discharge is still unknown, but may have been caused by high partial pressure of hydrogen.
  - We do know that reflected power interlock is essential to prevent deconditioning. This was implemented after problem started.

  - Failure recurred December 15th.
  - Measurement of gas species may help diagnose cause of breakdown if cause of poor vacuum is leak. Poor vacuum may be caused by ion pumps being saturated with hydrogen.
  - Vacuum should be improved as the poor vacuum is likely original cause of breakdown problem.
  - **Recommendation: Improve vacuum in present RFQ by replacing ion pumps with cryopumps to enable continued operation of the RFQ until it can be replaced.**
  - **Recommendation: Check the cooling water flow on the PISLs. Cooling channels are very small ~ 1mm diameter. If channel is blocked PISL could over heat and distort.**
  - A carbon copy of existing RFQ will likely suffer same discharge problem after similar use unless cause of breakdown was poor vacuum
  - **Recommendation: A new RFQ should be built, but the cause of the breakdown in the existing RFQ should be identified before proceeding. Once the cause of the breakdown is identified the design of the new RFQ should be modified as appropriate.**
- Backup RFQ: New design that can provide 50 mA for 1 MW operation should be considered.
  - Consider not using PISL for dipole suppression as they maybe causing the discharge problem, evidence indicates they may multipactor. Insufficient cooling coupled with heating from multipacting may have caused one or more PISLs to distort leading to high voltage break down.
  - PISLs cause the fields to scallop. That is; at the location of a PISL the electric field in the vane gap is depressed.
  - PISLs change the frequency of the Quadrupole mode making the RFQ more complicated to tune to the correct operating frequency.
  - 4 rod stabilizers do not change frequency of quadrupole mode. RFQ will operate at frequency calculated by Superfish for the RFQ cross section.
  - **Recommendation: Consider a new design for the backup RFQ, capable of 50 mA. The committee suggests 4 rod stabilizers on end plates similar to those used on LEDA instead of PISLs.**

Linac Energy Upgrade Plan

1 Introduction

The end of FY08 (March 31) is the official end of the J-PARC construction project and the foreseen milestones have been met by the project team. The RCS has recently demonstrated its capability to operate at 300 kW of beam power with 1 % beam loss and the Main Ring has accelerated protons up to 30 GeV and slowly extracted them. Users have begun exploiting the neutron facility, and the start of neutrino production is planned in April 2009.

Encouraged by this success and as part of a global stimulus package for the economy, the Japanese government has recently allocated to J-PARC the resources requested to pursue the increase in performance of the facility by upgrading within two years the linac energy to its design value of 400 MeV.

Asked for advice and recommendations, the ATAC has charged a subcommittee to investigate the matter. This section is the result of this analysis, based on the information collected during presentations and discussion with J-PARC staff on March 4, 2009 on the Tokai site.

2 Findings

Project management

The J-PARC facility has been planned to use a 400 MeV H^- linac injecting in the RCS. For budget reasons during construction, the linac energy has first been limited to 181 MeV, although the entire infrastructure (buildings, space in the tunnel, etc.) has been dimensioned to host the high energy part at a later stage. Moreover, the specific hardware required for that extension, like accelerating structures and high power RF components, has been the subject of development and prototyping since many years.

It is however clear that the requirements of the stimulus package impose demanding constraints to the J-PARC staff. A total of 43 Oku-yen has to be invested in approximately 50 construction contracts which have to be signed by the end of March 2009, and the project has to finish 2 years later.

Installation and commissioning of such a major extension will strongly impact on the operation of the facility. Their planning should result from negotiations with users, which have not yet begun.

To smoothly integrate and optimally contribute to the evolution of the overall J-PARC facility, the detailed inventory of the equipment to be built deserves further consideration and the coordination of the energy increase with other upgrade projects like the linac intensity increase to 50 mA must be carefully planned. It is clear that the RCS must be made capable of using the 400 MeV beam as soon as it is delivered by the linac. It is also clear that the linac intensity must be brought up to 50 mA to draw the benefit from the increased injection energy and for the RCS and MR to reach their nominal beam power.

ACS accelerating structures

After analysis of the J-PARC project requirements, and comparison with alternative solutions like Side-Coupled Structures (SCS), On-axis Coupled Structures (OCS) and Disk and Washer (DAW), Annular Coupled Structures (ACS) have been selected to equip the high energy part of the linac. The detailed parameters result from the optimization of beam dynamics and construction cost. The frequency of 972 MHz has been adopted for the 21 accelerating modules operating at 4.1 MV/m, each one consisting of 2 tanks of 17 cells, connected by a bridge coupler where the RF power is injected. In addition, 2 bunchers will be installed in the MEBT-2 and 1 or 2 debunchers in the L3BT (depending upon the requirements of the RCS).

The machining of ACS cells and their assembly process have been developed and tested during the past years. A buncher and a low beta accelerating module have been built and successfully tested at high RF power. A high beta module has been fabricated and will be fully tested in 2009.

A field tilt has been measured along the assembled structures, which is explained by an incorrect value of the coupling mode frequency after brazing. The proposed solution is to use 4 plungers per coupling cell to adjust the frequency after assembly. However, these plungers increase the risk of multipactor and anomalous heat dissipation in the coupling cell. Considering that an ACS cell is basically a wide disk, with a relatively small thickness, the change of frequency may result from an excessive pressure applied during the measurement before brazing or from the release of the stress generated during machining and remaining after the mild heat treatment. A better understanding can avoid the risks and complications associated with the additional plungers.

R & D is on-going to reduce the duration and cost of fabrication (high power tests in September 2009). Assuming two machine tools will be used, the fabrication of all the accelerating structures will take two years.

The vacuum performance is being improved taking into account recommendations from the previous ATAC report.

Beam dynamics

The 400 MeV J-PARC linac has been the subject of end-to-end simulations without machine errors. Transverse and longitudinal tunes have been selected which are remote from resonances, even at the highest beam current.

Knowledge of the longitudinal beam properties at the end of the separated drift tube linac (SDTL) would further help to check the validity of the parameters of the high energy section at the design stage. That information is unfortunately unavailable because of the absence of the necessary beam instrumentation (BSM).

The MEBT-2 section is designed to provide a smooth transition between the SDTL and the ACS section without ramping the accelerating gradient in the first part of the ACS linac. Two ACS-type bunchers and "quasi-doublets" lattice are used. An alternative solution providing a current-independent match could also be considered.

Emittance growth is moderate along the whole linac. The ratio of ACS aperture to rms beam size is close to 10.

Two debunchers are foreseen in the transfer line between linac and RCS, although the second one depends upon future beam dynamics studies in the RCS.

Detailed error studies have not yet been made. The proposed high-energy section of the J-PARC linac will have a higher peak current than existing accelerators of the same class. Hence the modes excited in the multi-cell accelerating structures by the transient beam current may be disturbing.

The periodic beam loading resulting from the chopping frequency of 1.2 MHz (RCS revolution frequency) will modulate the field in the ACS. Compensating with a modulation of the klystron power is likely to result in the excitation at uncontrolled level of other modes in the accelerating structures.

RF

The high power RF equipment for the energy upgrade consists of 24 Klystrons [972 MHz, 3.1 MW, 700µs, 50 Hz] with their DC cathode power supplies (7 units - 110 kV DC), mod-anode modulators and waveguide devices.

Three prototype 972 MHz klystrons have already been built and tested, the last one meeting fully the RF specifications. A fourth one of more compact dimensions and implementing the knowledge gained with the previous devices is under construction. It will be tested at high power during the first half of 2009. It should be representative of the future series of 24 required to drive the ACS structures. Their fabrication is foreseen at a rate of one klystron per month, which is incompatible with the deadline of the upgrade project of March 2011.

The cathode power supplies will be the same as for the 324 MHz klystrons of the low energy linac. The mod-anode modulators will be improved to remedy to the sporadic breakdowns observed with the present units.

An improved high power circulator with a better thermal stability has been designed and will be tested at high power in August 2009.

The low level RF and the distribution of the phase reference will be similar to those in the low energy linac. Similar electronics will be used, modified to operate at 972 MHz. Feedforward compensation is planned for the periodic transient beam-loading due to the beam chopping at the revolution frequency of the RCS. The principle has been tested on a low power set-up, but not yet on a complete linac RF system.

Beam Instrumentation

An extensive suite of beam instrumentation devices are foreseen, including Bunch Position Measurement (BPM), Beam Loss Monitors (BLM), Wire Scanners (WS), Fast Current Transformers (FCT), Bunch Shape Monitors (BSM) and Slow Current Transformers (SCT).

Time-of-flight measurements (TOF) are proposed for the longitudinal tuning of the linac. Their potential accuracy in the ACS linac remains to be carefully estimated and compared to the needs. Phase information will be derived from FCTs instead of BPMs. Considering that FCTs may suffer from the non-linearity of the ferrite and provide an amplitude dependent phase measurement, their use should be reconsidered.

BSM are envisaged for bunch length measurements, but their construction is not foreseen in the present definition of the project.

Beam losses are planned to be measured with BLMs using gas ionization chambers. Such devices are also sensitive to the X-rays produced by the RF cavities, which may confuse diagnostics. Neutron detectors are better alternatives.

3. Comments & Recommendations

The J-PARC project staff has already demonstrated its competence and has gained highly valuable experience realizing the present facility: the committee is convinced that it can successfully meet the challenges of the linac energy upgrade.

The J-PARC facility is ready to be equipped with the high energy part of the linac. The extensive R&D and prototyping that have already taken place provide the basis for immediate procurement of the necessary accelerator components.

Project management

- The committee considers that the official schedule is very tight and that special measures have to be taken to finish before April 2011: more than two machine tools must be used to manufacture the ACS disks and particular measures have to be negotiated with the klystron manufacturer(s) to bring the production rate up to 2 klystrons/month.

- The committee reminds that the RCS has to be upgraded to operate with injection at 400 MeV no later than the linac energy is brought up to that value.

- Recommendation: the coordination of installation and commissioning with facility users has to take place as soon as possible.

- Recommendation: the intensity increase to 50 mA should be phased for permitting a smooth increase of the performance of the accelerator complex.

Accelerating structures

The committee acknowledges the remarkable results of the ACS development, and praises the R & D on the simplification of machining that will significantly reduce construction time and cost.

- In the present context, the committee agrees that the ACS design meets the needs of the energy increase of the J-PARC linac, which has to provide an intense proton flux with a high duty factor (3 % nominal -15 % maximum), and hence with a large heat dissipation in the normal conducting accelerating structures. The frequency of 972 MHz is properly chosen.

- Recommendation: special care has to be taken to remove the stress and strain associated with the machining process of the ACS disks, in order to preserve dimensional accuracy. More heat treatment should be considered between machining steps.

- Recommendation: the addition of tuners to adjust the frequency of the coupling cells should be considered as a back-up measure. The committee recommends pursuing the study of the assembly, testing and brazing procedures in view of making the final result predictable.

- Mass production schedule is very tight and presently incompatible with the official project schedule if only 2 machine tools are used.

- The number of debunchers to be built should be determined from beam dynamics studies in the RCS. The committee emphasizes the need for this study to take place and conclude rapidly.

Beam dynamics

- The main parameters selected for the high energy section lattice like focusing period length and transverse and longitudinal tunes are adequate for a good control of beam quality. Overall, the design of the high energy linac is judged as conservative and safe: aperture is large, gradient is low, focusing is strong and the margin in terms of heat load is comfortable.

- Recommendation: error studies are required as soon as possible to define a final set of tolerances for all accelerator sub-systems [especially alignment tolerances for all elements and tolerances for the adjustment of the accelerating fields in the ACS module (field tilt, difference in average field between accelerating sections of the same module as well as between modules, length of tank and inter-tank space,…)].

- Recommendation: consider an alternative possibility for current independent matching between the SDTL and ACS, using an adiabatic transition for the wavenumbers of betatron oscillations.

- Recommendation: the detailed beam parameters of the SDTL linac should be measured as soon as possible in order to predict potential beam losses in the ACS section (linked to the recommendation for the installation of a BSM in the Beam Instrumentation section).

- Recommendation: don't modulate the klystron power at the chopping frequency of 1.2 MHz to try and compensate for the periodic beam loading effect. An alternative solution should be implemented to mitigate the effect of the modulated cavity field.

- The effect on beam of the RF field distortion during the beam current transient in the multi-cell accelerating structures deserves quantization.

RF

The committee is impressed by the development work concerning klystrons and circulators and congratulates the RF team for these achievements.

- The development and production of the 972 MHz klystrons is on a critical path: the expected fabrication rate of 1 klystron per month is incompatible with the official project planning.

- High Voltage discharges in the anode modulator have to be carefully addressed. The committee suggests implementing an oil cleaner to solve a potential contamination of the insulation oil by impurities or dust.

- Installation and adjustment procedures should be developed to work in parallel.

- Although the basic design concept of the digital RF feedback system has been proven in the low energy part of the linac, its implementation in the ACS section needs careful study of its specificities.

Beam Instrumentation

- The number and variety of beam instrumentation devices are sufficient for commissioning and operating the high-intensity J-PARC proton linac.

- The potential accuracy of TOF measurements in the high energy part of the linac has to be carefully estimated and compared to the needs.

- **The committee recommends to consider utilizing strip-line BPMs for phase measurements, rather than FCTs** and more specifically to contact J.D. Gilpatrick from LANL who has recently developed BPPMs (Beam Phase and Position Monitor) for high-intensity proton linacs.

- **The committee strongly advocates the installation as soon as possible of one BSM at the end of the SDTL linac, to address the needs of beam dynamics. For similar reasons, additional ones have to be foreseen inside the ACS linac.**

- The committee advises the use of neutron detectors as beam loss monitors, to allow distinction from X-rays produced by the accelerating cavities.

3 GeV Rapid Cycling Synchrotron

The 3 GeV Rapid Cycling Synchrotron(RCS) is located in a 348 m long tunnel and will provide proton beam to a high power neutron spallation target as well as to the 50 GeV Main Ring (MR). With a beam intensity of 8.3×10^{13} protons per cycle, a repetition rate of 25 Hz and an injection energy of 400 MeV, the RCS can deliver 1 MW beam power at the 3 GeV extraction energy. The lower injection energy of 181 MeV, which is part of the present Phase I construction project, reduces the beam power of the RCS to .33 to .6 MW (2.6-4.8×10^{13} protons per cycle). At the upper end of this range the beam loss is likely to exceed beam loss limits in the RCS and in the transport lines to the neutron spallation target and the Main Ring.

Since the last A-TAC meeting the RCS has been operated for the neutron and MLF users program and beam was delivered to the MR for the successful commissioning of first acceleration to 30 GeV and first slow extracted beam to the hadron experimental hall. The RCS operated for up to one hour at 100 kW and for 70 seconds at 215 kW with 25 Hz repetition rate. Present continuous operation is limited by the front end to about 20 kW.

Comments and Recommendations

- High intensity operation of the RCS was tested in detail using single pulse mode. Transverse phase space painting was studied using orbit analysis and turn-by-turn profile measurements. The measurements show excellent agreement with expectations. Longitudinal painting and set-up of the 2nd harmonic rf was successfully tested and improved the bunching factor from 0.2 to 0.4. The beam intensity loss over the first few milliseconds for various conditions of longitudinal and transverse painting and various injected intensities compared quite well with multiple particle tracking calculation that includes space charge as well as the multi-pole components and field and alignment errors of the dipoles, quadrupoles, and sextupoles, and the measured power supply tracking errors. The commissioning team is to be congratulated for the very quick set-up and beautiful verification of the painting schemes of injection into the RCS.

  With optimum painting and optimum parameters for the 2nd harmonic rf the beam loss, as measured with the beam current transformer, was about 1% for a beam intensity of 2.6e13 protons per pulse. This would correspond to about 310 kW for continuous operation at 3 GeV and 25 Hz repetition rate. All the loss occurred during the first 1.5 ms of the acceleration ramp. Note that this would correspond to 180 W of lost beam power, well within the 4 kW limit of the RCS beam collimation system. If this beam loss can indeed be localized to the collimator this would demonstrate the 300 kW beam power capability of the RCS and extrapolation to 600 kW would be plausible.

  Recommendation: Determine the loss distribution in the RCS for high intensity operation and localize losses in the collimators.

- The non-linear leakage field of the extraction septum and extraction beamline magnets have been identified as a significant limitation to the dynamic aperture of the RCS at injection. After successfully shielding about 40% of the leakage field the early beam loss could be reduced by over a factor of two. This clearly demonstrated the importance of correcting non-linear fields in the RCS at injection energy. This can be done either by local correction in the case of the extraction septum or, more generally, with 2nd and 3rd order DC "stopband" correctors that can open up the betatron tune space for the tune footprint of the high intensity beam at injection energy.

Recommendation: Consider installing 2nd and 3rd order DC "stopband" correctors.

- Significant degradation in the shunt impedance of one out of three gaps of rf cavity # 7 was measured starting at about August 2008. The cavity had to be run with only two gaps. Later inspection found that all six Magnetic Alloy (MA) cores corresponding to this gap show some damage with two cores showing severe damage. Although this type of core damage was observed in earlier cores it was thought to have been fixed by improving the core manufacturing. The project plans to replace the six damaged cores of cavity #7 and re-install it in the ring at the end of March. 18 new cores are being manufactured for installation in cavity #7 during the summer.

Recommendation: At the earliest opportunity inspect cores of gaps that presently don't show impedance degradation and verify that there are no signs of damage.

Recommendation: Prepare a spare RCS rf cavity with new cores that can be used in the future to replace a failing cavity in the ring.

- Measurements of the longitudinal and transverse impedance of the RCS extraction kicker system that included the powering cable and the pulse forming network agree reasonably well with calculations and show values for the transverse impedance of up to 10^5 Ohms/m, mainly due to reflections in the cable. This is significantly above the calculated instability threshold. Possible schemes to suppress the reflections were discussed. It is difficult to accurately predict whether this impedance will actually lead to instabilities in the RCS. However, contingency plans for this possibility should be developed as soon as possible, which could include the construction of a transverse damper and/or a redesign of the RCS extraction kicker.

Recommendation: Prepare plans to address beam instabilities caused by the large kicker impedance.

- The extraction kickers have been installed without coating the Ferrite and aluminum surfaces with TiN. These surfaces have large Secondary Electron Yield (SEY) coefficients, which can only be improved by coating them. Although it is not practical to coat these surfaces at this time preparations should be made to coat the kicker surfaces in the future.

Recommendation: Prepare for coating the Ferrite and aluminum surfaces of the extraction kicker. Coating with TiN was successfully achieved for the SNS project.

50 GeV Main Ring Synchrotron Status & Commissioning Plan

First beam injection into MR and extraction to the injection dump with 3 GeV was performed over May 19-24, 2008, accompanined by beam storage of 1 second. Over June 14-21 the MR received government inspection on radiation protection, sharing with the beam with MLF. During initial operations, very large common mode noise was detected within the power supply systems that caused serious problems. These were removed in the summer shutdown by changing cabling among dipole and quadrupole magnets. By such improvement, the tune deviation at injection was reduced from 0.1 to 0.01, which contributed to successful beam acceleration from 3 GeV to 30 GeV and fast beam extraction to the abort beam dump on the 23rd, February, 2009. On the 29th, January, 2009, the proton beam with the intensity of 1.3×10^{11} was slow extracted and guided to the hadron beam dump. Extraction efficiency is estimated larger than the 90 % with the error ~10%. Congratulations to the J-PARC commissioning group for such a quick success of acceleration!!

Although the power supply of quadrupole magnet suffered damage of 4 diodes adjacent to IEGT, the fast beam extraction test to the neutrino target is to be performed in coming April or May and beam delivery to the users for neutrino conversion experiment is scheduled from coming September. For neutrino operations with fast extraction, more than 300 kW RCS power will be needed to provide 100 kW beam power for neutrino production in the coming autumn because only 6 bunches will be acceptable into MR in 3.64 second cycle due to the limited rise time of the presently available kicker magnet. The betatron tune variation with time is ±0.03 due to current ripple of 3×10^{-3} in the quadrupole magnet power supply, which needs to be reduced for realization of the slow extracted beam with good time structure.

Improvement of beam collimation to tolerate up to 5 kW loss has been proposed for the second stage to realize the beam power of 750 kW.

Comments and Recommendations

The origin of the power supply breakdown is to be clarified as soon as possible in collaboration with the maker together with the improvement to reduce the ripple both in injection flat base and flat top.

A scheme utilizing a separate power supply with lower power for the flat top to reduce the ripple during beam extraction as adopted in BNL is worth investigating in case a better time structure for slow extracted beam is required from the users.

> **Recommendation: Consider a dedicated low voltage supply for regulating current at flattop.**

Reduction of the repetition cycle is to be investigated carefully in connection with the attainable tracking error, rising time of available kicker magnets etc. Acceleration time should be carefully studied in connection with 600 Hz ripple.

The lifetime of MA cut core loaded RF cavities should be carefully considered in connection with the situation of uncut core in RCS.

Recommendation: Prepare an additional MR rf cavity, bringing the total number to 6.

For the second stage with higher beam power, further detailed investigation on feedback damping of transverse instability is required.

For realization of the design goal beam power, the optimum scheme of the beam energy and repetition cycle is to be studied in connection with the characteristics of the fabricated dipole and quadrupole magnets and RF cavities.

The beam orbit of slow extracted beam is to be studied to avoid the beam loss at septum magnets which is avoidable when beam study becomes possible.

Beam loss and residual radiation from the ion source to the beam dump of extracted beam are to be summarized in evaluating attainable beam power in the final stage.

Recommendation: The commissioning team should move toward commissioning with high intensity (100 kW equivalent) single beam transfers from the RCS to the MR as soon as possible.

Transition to Operations & Power Projections

Significant progress has been made in beam commissioning meeting previously projected milestones. The RCS was operated at the extracted proton beam power of 310 kW for a single cycle with a beam loss of about 1%, 200 kW for about 70 seconds, 100 kW for an hour, and 20 kW routinely. Reachable beam power is first limited by the RCS beam dump (4 kW) before the MLF received beam and, after December 2008, by the discharge problem of the RFQ. The MR accelerated the beam to 30 GeV energy and delivered beam to the neutrino and hadron experimental areas via fast and slow extraction methods, respectively.

A budget of 43 Oku Yen was approved, about 50% of the requested amount for linac upgrade to 400 MeV, to be completed officially by JFY2010 and practically by JFY2011.

Comments and recommendations

- With approval of an aggressive schedule for linac upgrade, the transition to operations is closely linked to the linac energy upgrade plan. Projection of the beam power for the user community needs to take into account the actual execution plan of the linac energy upgrade and the mitigation plan of exposed problems pertaining to e.g. the RFQ, the RCS and MR RF cavity, the MR power supply ripple, and the foreseen uncontrolled beam loss.

  Recommendation: Develop a plan of commissioning towards operations in accordance with available resources to upgrade the linac energy and to mitigate exposed problems; project beam power accordingly.

- The curves presented showing anticipated power delivered from the RCS over the next six years provide a useful tool in providing a context for organizing efforts aimed at improving performance and communicating expectations to the user community. This presentation would be enhanced by providing the projected MW-hours available over the next several years.

  Recommendation: Integrated beam power projections over the next several years should be developed for the RCS and MR.

- Coordinator for accelerator commissioning needs to lead the effort in developing an integrated plan for transition towards operation. For example, as the linac energy is increased, function of the linac-to-RCS-beam-transport becomes increasingly important. As the beam power is increased, activation at the debunchers, which were positioned upstream of the L3BT transverse collimators, may be exposed to excessive radiation. Activation in the L3BT bend may also be of concern. (SNS HEBT momentum collimator/dump were damaged after the device of 2.5 kW design power limit was exposed to excessive beam power of 9 kW for an extended period of time.) Optimized use of L3BT may enhance the overall performance of the accelerator complex.

  Recommendation: Commissioning efforts should be coordinated integrating all systems of the accelerator complex to strategically meet the projected goals of the commissioning plan.

- As beam commissioning progresses, a list of upgrades may be identified to maximize the potential of the accelerator facility. For example, beam commissioning experience indicates that beam loss in the RCS is sensitive to the control of machine tunes. It is thus speculated that implementation of trim quadrupoles and other stop-band correctors may significantly enhance the performance of the ring, in particular during high intensity operations.

Recommendation: Develop a roadmap to maximize the potential of accelerator complex.

- Spares is an outstanding issue affecting commissioning progress and project cost. Analysis was presented on the linac klystron systems, and on RCS RF cavity cores. The effort needs to be extended to other systems of the facility where spares are needed. As we recommended at the previous reviews, a formal document containing performance risks, mean-time-between-failure, procurement lead time, and cost of all major components can be important both in the planning and in convincing the funding agencies.

Recommendation: Establish a spares strategy based on a risk analysis incorporating mean time between failure (MTBF), performance impacts of failures, fabrication/procurement lead times, costs, etc. Such a strategy should be used as a basis for establishing the spares component of the operations budget.

Appendix: Meeting Agenda

ATAC2009 Agenda

March 5, Thursday

time		period (min)	Category	Title
820		*Bus starts at 8:20 from hotel to meeting place.*		
855	915	20	Time for LAN connection	
915	935	20	**Project status**	
935	1005	30	**Accelerator Overview**	
1005	1040	35	**Executive session**	*closed session*
<< coffee break >>		20		
1100	1130	30	**Linac**	Status of the Linac
1130	1200	30		Status of the RFQ and Backup Project
<< lunch >>		80	*(JAEA Cafeteria)*	
1320	1340	20	**RCS**	Status of the RCS
1340	1420	40		Beam Commissioning Results for the RCS
1420	1510	50	**Ring RF**	Status of the Ring RF
				Alternative Solutions for the Ring RF Cavity Structures
<< coffee break >>		20		
1530	1600	30	**Control**	Status of the Control System
1600	1730	90	**Linac energy upgrade**	Outline of the ATAC Subcommittee for the Linac Energy Upgrade
				Subcommittee's Analysis
1730	1820	50	**Executive session**	*closed session*
<<RECEPTION>> 1900 - 2030 (Bus starts at 18:40 from meeting place to restaurant)				

March 6, Friday

time		period (min)	Category	Title
820		*Bus starts at 8:20 from hotel to meeting place.*		
840	910	30	**Executive session**	*closed session*
910	940	30	**MR**	Status of the MR
940	1010	30		Beam Commissioning Results of the MR
1010	1030	20		Slow Extraction
<< coffee break >>		20		
1050	1140	50		Magnet - Power Supply
				Magnet - Field Measurement
1140	1210	30		Fast Extraction
<< lunch >>		80	*(JAEA Cafeteria)*	
1330	1400	30	**Impedance and instability**	Impedance and instability
1400	1610	120	**Tour J-PARC**	(MLF, MR Experimental Facilities and HENDEL (ring RF-cavity))
1610	1730	80	**Executive session**	*closed session*
<< dinner >> 1810 - 2000 (Bus starts at 17:50 from meeting place to restaurant)				

March 7, Saturday

time		period (min)	Category	Title
840		*Bus starts at 8:40 from hotel to meeting place.*		
900	1100	120	**Executive session**	*closed*
1100	1200	60	**Report to project team**	
<< lunch >> 1240 - 1340 (Bus starts at 12:20 from meeting place to restaurant)				

adjourn