21 March, 2014

Report from the 2nd Meeting of the XMAC (PIP-II Machine Advisory Committee)

February 25-27, 2014
Fermilab

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1. Introduction

The XMAC held its second meeting on February 25-27, 2014, at Fermilab. XMAC now designates the "PIP-II Machine Advisory Committee".

The Committee members present at this meeting were: Rick Baartman (TRIUMF), John Galambos (ORNL, SNS), Roland Garoby (CERN - chair), Kazuo Hasegawa (JAEA, J-PARC), Sang-Ho Kim (ORNL, SNS), Deepak Raparia (BNL), Yoshi Yamazaki (MSU).
Jie Wei (MSU) and Hans Weise (DESY) could not attend.

The XMAC is thankful to the Fermilab management and staff for the quality of the organization and especially appreciated the effort invested by all the presenters to prepare clear and comprehensive talks. The availability of the slides before the meeting allowed for a proper preparation, as well as the written reactions to the recommendations from the previous meeting.
The Committee found that 2.5 days are well matched to the goals of such a meeting and recommends adopting this duration for the future meetings.

2. Executive summary

Overview: evolution from Project X to PIP-II

The plans of Fermilab have been revised during the fall of 2013, as a result of the strategy decided by the new laboratory director and of the financial guidelines from the DOE. Taking neutrino physics as the main goal of the laboratory in the next decade, the objective is to satisfy the LBNE requirements as soon as it is operational, namely to deliver 1.2 MW of beam power on target at 60-120 GeV in 2023.

The affordable cost of the accelerator modifications being limited, a new proposal ("PIP-II") had to be prepared, less ambitious and costly than Project X, but dedicated to the objective of bringing the beam power of the MI up to 1.2 MW. Considering that the physics uses of Project X remain of high potential interest in the longer-term future, it is natural to re-use part of Project X in the new proposal. PIP-II is therefore based on the first 800 MeV of the Project X linac operating in pulsed mode and replacing the present 400 MeV linac as injector of the Booster. Combined with the proper upgrades, the objective is to increase by 50 % the intensity per pulse of all synchrotrons (Booster, RR, MI). Extensive consolidation must also be foreseen to allow for a reliable operation of these machines beyond 2030.

After completion of PIP-II in 2023, when LBNE will become operational, the main Injector will hence be capable to deliver 1.2 MW of beam power on target while the other users will continue to be supplied with an adequate flux of protons. Extension can later be made to increase beam power from the Main Injector beyond 2 MW and to address the needs of new experimental facilities requiring a continuous beam with the other accelerators.

The targets and target areas will be part of the LBNE work programme and don’t need to be addressed during this meeting.

Comment

PIP-II is a remarkable illustration of the flexibility and creativity of the Fermilab staff aiming at:

- an “affordable” first step for meeting the needs of the LBNE as soon as it enters in operation while maintaining a rich physics programme with lower energy protons.
- a worthwhile investment for the future, with the potential to further increase the MI beam power and to supply a continuous beam at intermediate energies to new physics experiments.

Q1: Design Concept: Does the PIP-II conceptual design represent a viable concept for a high intensity proton facility meeting the enumerated performance goals?

YES, the concept is likely to meet the performance goals.

- PIP-II design profits from the work accomplished for Project X. It will benefit from the already started development like PXIE and from the R&D on superconducting RF.
- PIP-I upgrades and consolidation to the Booster are fully relevant for PIP-II.
- PIP-I investment in the present Linac will be useless after PIP-II.

R1: Prepare a revised PIP-I plan in case PIP-II is approved.

- Preserving the capability of CW operation in the long-term future has large design consequences and increases the challenges (more details in the last section of this report).

R2: Get confirmation that the physics needs for continuous beam are essential in the long-term future.

- For a given beam power, operating the MI at lower energy necessitates a proportionally larger proton beam flux. Beam losses taking place mostly in the low energy part of the cycle, they will increase by the same factor.
- The baseline plan for locating the 800 MeV linac makes good use of the existing infrastructure and minimizes construction cost.
- The present siting can be further optimized.

Q2: Risks: Have the primary areas of technical and cost risk associated with the design concept been identified?

- The technical risks associated with the 800 MeV Linac are rather convincingly treated in the proposed work plan. The only exception is the stabilization of the field in the cavities in pulsed mode, which will extensively depend on LFD compensation by piezo tuners.

R3: Plan for injecting slightly below 800 MeV to be able to compensate for a faulty cavity.

- The goal of achieving a reliable operation of the Booster, RR and MI during the next 20 years deserves a careful analysis of the probability and impact of the risks, in view of establishing priorities for consolidation. To our understanding such an analysis has been done for the Booster in the context of PIP-I, but not for the RR and MI.

R4: Plans for consolidation in RR and MI should be based on an exhaustive and quantitative analysis of the risks.

- Performance of slip stacking in the RR with 50 % more beam intensity and at constant beam loss power is a major uncertainty.

R5: Demonstrate with realistic simulations that slip stacking in RR at high intensity can be achieved with the acceptable loss budget. Identify the resulting requirements for equipment and for the beam from the Booster.

- It remains to be proven that the MI can capture and accelerate 50% more beam per pulse after PIP-II with similar beam loss power than today (or even less if MI ejection is lower than 120 GeV).
- Capturing and accelerating 50% more intensity in the Booster with bunches of 0.08 eVs instead of 0.12 eVs today is a challenge.

R6: Test production and preservation of low emittance bunches in the Booster and their capture in the MI at the highest possible intensity. Proceed with extensive simulations and benchmark results with experimental observations.

- The design of charge exchange injection at 800 MeV in the Booster over 300 turns, with 50% more intensity and the same beam loss power as today is in itself a challenge and a major technical risk.

R7: The design of a proper 800 MeV injection layout fitting in the available space is critical for gaining confidence in achieving PIP-II goals.

- Accurate and dependable beam instrumentation is essential for characterizing beam in all accelerators.

R8: Make sure that beam instrumentation is adequate for supporting investigations and studies in the existing accelerators.

- The use of "Total Loss Monitor" (TLM) is promoted as a means to accommodate a reduced shielding. The MPS requirements shown to the committee were preliminary.

R9 : The operational consequences of the combined use of TLM and shielding deserve in-depth analysis. The requirements for the MPS have to be refined

- The total cost of PIP-II is estimated at 540 M$ (excluding target and synchrotron rings). The cost to the DOE is estimated as 380 M$, assuming that 160 M$ would be provided by external collaborations.

R10: Prepare back-up plans in case the external contributions do not reach the expected level.

Q3: R&D Plan: Is the R&D plan properly directed at addressing the identified risks in an effective manner? Are the risks appropriately prioritized and will the completion of the R&D plan provide a basis for proceeding to the construction phase with confidence that performance goals can be met?

- The R&D plan for the Linac, including PXIE and SRF, is comprehensive but still aimed at CW and high power operation. Consequences of pulsed mode operation would deserve more efforts (e.g. piezo tuners).
- The monitoring of beam loss at low energy is important and notoriously difficult. The committee strongly supports the R&D on CVD diamonds beam loss detectors.

R11: The highest priorities in the development of Linac beam instrumentation should result from the needs of PIP-II at injection in the Booster.

Q4: Plan to prepare for construction: To what extent are the deliverables of the R&D plan necessary to complete prior to construction? Can or should some elements of the plan be carried out in the construction phase? If available resources do not support the complete pre-construction plan, which elements should be considered highest priority for available funding?

- Most SRF development and prototyping for SRF cavities except SSR2 are very advanced either in the USA or in India.

R12: If resources are short, the construction of an SSR2 prototype could be delayed as well as the construction of the 6 cavity high beta cryomodule.

- The development of the MEBT choppers does not need to be finished at the start of PIP-II in 2018.

R13: If resources are short, the development of the MEBT choppers could be delayed until the start of construction of PIP-II.

Additional possibilities of cost savings

The Committee suggests investigating the following issues as potential means to reduce the cost of construction:

- S1: Profit from the pulsed mode to operate the Linac cavities at higher field. Less cavities would be needed to reach 800 MeV, but more powerful RF amplifiers should be installed. The typical goal should be to build one less high beta cryomodule.

- S2: Consider the possibility to reduce the Linac energy.

3. Complementary observations and reactions

Global concept

Findings

Neutrino physics is now the stated priority for FNAL's scientific output, with a beam power at 120 GeV planned to exceed 1 MW, even for energy as low as 60 GeV. The plan is to increase the beam intensity of the Booster by doubling the injection energy to 800 MeV. The possibility to extend the present linac was rejected in favor of a new superconducting linac because the former would not allow eventual CW operation. The price difference is approximately 150M$.

In the current PIP-I which will be completed in 2016, the RF systems of the 400 MeV linac will be renovated and the Booster is being upgraded to be capable of delivering beam at 15 Hz. The goal is to deliver a beam power of 80kW at 8GeV and 700kW at 120GeV.

The total cost of PIP-II is estimated at 540 M$ (excluding target and rings). The cost to the DOE is estimated as 380 M$, assuming that 160 M$ would be provided by external collaborations.

Observations

The PIP-I investments in the Booster are fully relevant for PIP-II. This is not the case for the present Linac, which will stop being used after completion of PIP-II.

The imperative of CW operation has major consequences both for the Linac and Booster. The CW-capable front-end results in a current of 2mA, relatively low compared with other high-power facilities. In the superconducting accelerating structures it results in a reduced gradient and a smaller 3 dB bandwidth making field stabilization in pulsed mode a difficult challenge. In the Booster, injection will take more than 300 turns, an order of magnitude more than has been achieved so far.

The amount of external in-kind contributions is high.

Recommendations

R1: Prepare a revised PIP-I plan in case PIP-II is approved.

R2: Get confirmation that the physics needs for continuous beam are essential in the long term future.

R10: Prepare back-up plans in case the external contributions do not reach the expected level.

Linac

Findings

The linac design is derived from Project-X. The same structure types are incorporated in PIP-II, although with a final energy limited to 800 MeV. Much of the previous linac design effort is retained.

The development of the HWR section is progressing well, with the delivery of all 7 cavities expected this year. The other cold mass components (BPM, tuners, couplers) are also well advanced and ready for procurement. The cryomodule design is based on an existing quarter wave resonator experience. If funding is available, the full cryomodule could be ready for PXIE in 2017.

The SSR1 development is also progressing well, with 2 K performance of 9 cavities exceeding requirements. Other cryomodule / cold mass components are in various stages of development and prototyping, with an expected delivery by early 2017. The SSR2 structure is less developed, but the knowledge base from SSR1 should be applicable.

The design of the high and medium beta 650 MHz elliptical cavities is essentially complete with single cell medium beta prototypes and full cavity high beta prototypes produced.

Comments

Thanks to the R&D effort launched for Project-X, design and prototyping of linac components is well advanced. There is a good likelihood of success of the linac. Even if the final energy of 800 MeV is not met, stable operation should be possible close to this value. The PIP-II beam power requirement is rather low (~ 16 kW), which reduces the immediate operational concern for extreme beam loss control.

Using the previously chosen Project-X family betas for the 800 MeV PIP-II mission may not be optimal. For this reduced output energy, it would likely be possible to redesign the linac and eliminate an SRF family type. However, given the effort already expended on developing the five SRF structures, and for preserving the possibility to ultimately build the Project-X linac, reducing the SRF families now may not be cost effective.

A superconducting RF linac is not the optimum technology choice for the PIP application of 1% beam duty factor and low current (2 mA). The primary motivation for superconducting RF technology is to support future CW applications. It is important to elucidate these CW applications, and determine some intermediate higher duty factor applications as soon as possible to consolidate the SRF choice.

PXIE is a good platform to test the front-end / low energy structures with beam, and get an early start using systems needed for PIP-II in an integrated fashion (e.g. controls, instrumentation, LLRF, MPS, …). The Committee encourages this effort.

Multi-particle linac simulations were not shown during this review, although their results are crucial for realistic Booster injection simulations.

A scheme to optimize the cavity Q_{ext} for pulsed operation is underway. This is a good idea, which can mitigate the impact of the long cavity fill time for pulsed operation.

Recommendations

R2: Get confirmation that the physics needs for continuous beam are essential in the long-term future.

Lorentz Force cavity detuning is a critical issue for the pulsed linac operation. Piezo compensation demonstration using automated learning feed-forward is underway using available pulsed cavities. Development of reliable piezo compensation mechanisms for all the PIP-II structure types is needed. A fall-back plan for failed piezo tuners could be to detune failed cavities and operate at a slightly lower Booster injection energy. Implications for this approach should be investigated to better specify piezo reliability requirements.

R3: Plan for injecting slightly below 800 MeV to be able to compensate for a faulty cavity.

Rings

Findings

The objective of PIP-II is to bring the beam power from the MI up to 1.2 MW. This will be achieved by increasing the intensity per pulse in the MI, RR and Booster by 50%.

This result has to be obtained without increasing the beam loss power, hence by reducing the percentage of loss in all machines although the intensity will be larger. This is made even more severe considering that the Booster will operate at twice the present rate after PIP-I.

The RR and MI have to deliver 50% more intensity while maintaining the same loss from slip stacking, requiring the stacking efficiency to increase to 97% from 95%, and requiring tighter beam specification out of Booster. To reach that goal, it is estimated that the longitudinal emittance of the Booster bunches shall be 2/3 of that which is currently achieved, increasing further the challenge.

To run the MI at lower energies (60 GeV) will require the RR 53 MHz stacking cavities to operate in CW mode and will need a new design with higher R/Q and active beam loading compensation.

To accelerate higher intensity, the MI RF will need higher power. Two options were identified; (1) double number of RF tubes, (2) a new, more powerful tube (EIMAC 4CW250,000B).

SYNERGIA simulations with realistic space charge simulations are underway to understand losses with higher intensity beam in RR and MI.

Observations

The goal of achieving a reliable operation of the Booster, RR and MI during the next 20 years deserves a careful analysis of the probability and impact of the risks, in view of establishing priorities for consolidation. To our understanding such an analysis has been done for the Booster in the context of PIP-I, but not for the RR and MI.

In the Booster, the low linac current of 2 mA will result in a 300 turns injection process. Extensive studies and simulations will be necessary to demonstrate viability. The design of an 800 MeV injection region fitting in the available space remains to be done.

One of the successes of PIP-I has been to reduce activation by creating a kicker gap in the circulating beam. However, this results in a spectral component of the beam current that may trigger different coupled-bunch oscillations and render the required reduction by a factor of 2/3 of the longitudinal emittance even more difficult to achieve.

The Booster will thus likely require considerably more active damping to control the longitudinal emittance. It is not clear that the existing longitudinal wideband active dampers will be sufficient. The Committee took note that the electronics is being modernized and that the new system will be commissioned in the near future. Early investigations and experiments are encouraged.

A transverse bunch by bunch damper has been built which is expected to stabilize the beam and allow operation at much smaller chromaticity. The committee is confident that this device will be instrumental to bring up the performance of the Booster.

Interaction between intense bunches during stacking in RR must be extensively simulated to understand the evolution of these complex particle distributions.

Detailed simulation for transition crossing and electron clouds at 1.2 MW are encouraged.

Recommendations

R4: Plans for consolidation in RR and MI should be based on an exhaustive and quantitative analysis of the risks.

R5: Demonstrate with realistic simulations that slip stacking in RR at high intensity can be achieved with the acceptable loss budget. Identify the resulting requirements for equipment and for the beam from the Booster.

R6: Test production and preservation of low emittance bunches in the Booster and their capture in the MI at the highest possible intensity. Proceed with extensive simulations and benchmark results with experimental observations.

R7: The design of a proper 800 MeV injection layout fitting in the available space is critical for gaining confidence in achieving PIP-II goals.

Cryogenics

Finding

The design concepts are based on the maximum utilization of the existing cryogenic facilities in Fermilab (CHL, satellite refrigerators, LN2 systems). Two warm vacuum pumping skids will be used for 2K operation at a capacity of ~500W for the PIP-II pulsed operation. Typically the 2K operation will provide pressure stability better than 0.1 Torr in short time frame and better than 0.3 Torr in long term time frame. The helium transfer line will be designed to support CW operation.

Cryogenic load estimation seems to have a reasonable margin under the assumptions available. The load estimation could be changed as detailed design progresses and will require continuous iteration. One or two additional vacuum pumping skids could be easily added as needed.

Shielding and machine protection

Findings

Shielding assessment is going forward. Preliminary shielding assessment for PIXIE is complete for 15 MeV, up to 30 kW. Multi stage shielding assessment for no beam of cold SSR1 (Stage 1) and HWR (Stage 2), and final PXIE (Stage 3) is proposed. Final choice of the Linac shield design is determined by the safety analysis.

Goals and scopes of the MPS are defined to protect the accelerator from beam-induced damage and to provide overview of machine status. The MPS system will be developed based upon existing, proven systems such as used in ASTA and SNS. There are several technical concerns for the MPS: allow for CW as well as pulsed modes, low sensitivity of loss monitor at low energies, etc.

Observations

Total Loss Monitor (TLM) system has been developed and will be used in conjunction with passive shielding. This is planned to reduce passive shielding requirement by active disabling of beam.

LEBT, RFQ, and low power beam dump (5 mA H^-, 2.1 MeV) will be added to ion source in a next step. Calculations show that the radiation hazard due to 2.1 MeV H^- beam and x-rays is not significant.

Beam loss in the SC linac is estimated to be below 0.1 W/m in normal condition. Shield thickness can vary as a function of beam energy along the length of the SC linac enclosure. The accident condition is assumed at 1 W/m, a factor of ten with respect to normal condition.

In the 800 MeV beam transport line, 0.1 W/m for the accident condition is taken as starting point for the safety analysis.

The existing Booster minimum shield is 13.5 feet. Some shielding assessment effort was applied in 2013. Results are consistent with the Sullivan method within a factor of 2.

400 MeV controlled beam loss was established. The premise of the PIP-II plan for Booster is that present beam power losses must not grow. If that condition is observed, the existing shielding will be sufficient when complemented by the TLM system.

Booster injection region losses will deserve careful attention. Typical number of injected turns is presently 12 to 13, while 300 or more will be used in PIP-II. Moreover, injection energy will increase from 400 to 800 MeV. Local in-tunnel shielding might be necessary.

Shielding for the Booster to Main Injector beam transport line is a minimum of 24.5 feet. The TLM system used in conjunction with this shield should provide a robust protection for multi-megawatt beam power.

The MPS needs to integrate with several subsystems and a wide range of time scales (from nanosec to sec). The MPS study for PXIE is presented. It is to develop an understanding of acceptable loss rates in the warm section and detection of beam loss in cryomodules, and to develop understanding of low energy beam loss mechanisms and their instruments, etc.

The damage potential and response time due to the beam loss are evaluated. The design goal for MPS response time is presently 10 µsec by analogy with the SNS design basis.

CVD diamonds loss monitors are being investigated because of their sensitivity to single particles, nanosecond time response and their excellent resistance in high-radiation environments.

The beam loss monitoring remains to be precisely defined, especially for the low energy part (2.1MeV to 180MeV).

Comments

The TLM system has many potential advantages. Its connection to existing radiation safety system is expected to be approved by ESH&Q Section.

Some safety analysis is expected to have TLM results. To reflect the results, scheduling and reliable operation experiences are needed.

Beam loss assumptions in the Linac of 0.1 W/m for normal and 1 W/m for accidental condition are reasonable. For the accident condition in 800 MeV beam transport line, however, 0.1 W/m is optimistic.

The monitoring of beam loss at low energy is important and notoriously difficult. The Committee strongly supports the R&D on CVD diamonds beam loss detectors.

Recommendations

There is a risk that the TLM system, in its role for radiation protection, may trigger beam interruptions at an excessive rate. The operational consequences of such a choice deserve in-depth analysis.

The requirement of the MPS seems not clear to the committee. Needs shall be collected and requirements summarized. Close communication with the machine group is important. The time line of the development and implementation should also be shown.

R9 : The operational consequences of the combined use of TLM and shielding deserve in-depth analysis. The requirements for the MPS have to be refined

Conventional facilities

Findings

The proposed linac location looks appropriate, being close to existing utilities and infrastructure and minimizing environmental impact on wetlands. At the same elevation as Booster and Tevatron, the linac gallery and tunnel are long enough to allow for later increasing the energy up to 1 GeV.

Comments

The proposed layout is only a draft, which deserves further optimization.

Front end

Finding

The front-end systems will be operating in CW mode but beam will be pulsed at 0.9% duty factor with a LEBT chopper.

The first part of LEBT is intended to be fully space charge neutralized, while the part near and downstream of the chopper is not. This results in different beams at the RFQ entrance in the bunched case than in the CW case.

The lifetime of the source is 300 hours; having two sources combined with the help of a dipole in the LEBT will mitigate this issue.

The MEBT Chopper is capable to select the beam bunch-by-bunch. This capability could be used for bunch to bucket transfer and longitudinal painting at injection in the booster.

The transition from warm to superconducting technology occurs at 2.1 MeV, the lowest transition energy ever used in a proton accelerator.

Comments

The short lifetime of the ion source is an issue. Continuation of R&D to increase this lifetime is encouraged.

In the LEBT, the control of neutralizing particles is intended to be achieved with biased apertures. This will require experimentation to find the optimum setup, but is not expected to be an issue. The committee endorses the setting of the goal of PXIE, both CW and pulse mode LEBT,

Operating the RFQ in CW is most challenging. The Committee notes that the choice of RFQ parameters is conservative for this reason.

The transition energy of 2.1 MeV from warm to cold was based on required CW operation, but it is not expected to be an issue for 2 mA peak beam current.

The LEBT with three solenoids, one bending and some diagnostics is a suitable mockup for PIP-II.

Stepwise RFQ beam commissioning is reasonable.

The PXIE program is still aimed at CW and high power operation. The consequences of pulse mode operation would deserve more efforts in the pre-construction phase of PIP-II.

The choppers development is essential for CW operation, but much less for PIP-II.

Recommendations

R13: If resources are short, the development of the MEBT choppers could be delayed until the start of construction of PIP-II.

Superconducting RF

Findings

The scope of the effort consists of the design, fabrication, testing, and installation of nineteen cryomodules along with the related R&D efforts. No spare cryomodule is considered. The linac will be capable of CW operation at a later stage. In the context of PIP-II the HWR and SSR1 will be running in CW, all others SRF structures will be running at 5% RF duty factor with a beam duty factor of 0.9 % (2mA, 0.6 ms, 15 Hz).

The HOM spectrum in pulsed mode is denser than in CW mode but the amplitude of the sidebands is low. The chance of a resonance hitting a main spectral line is also very low. Therefore no HOM damper will be necessary.

There is an imbalance or inefficiency between RF duty factor, cryogenic dynamic load, beam current, and beam duty factor, which weakens the justification to use superconducting accelerating structures for the proposed pulsed operation. Physics demand and timelines for higher duty or CW operation need to be diligently developed.

Layout and RF parameters of SRF structures are those defined for Project-X such as frequencies, types of cavities, and transition energies. Peak surface fields are reasonably set for the CW operation. For the pulsed operation the achievable gradient would be higher.

The cryomodule design for the elliptical cavity section is of the DESY-style although with cold to warm transition at each end. A separate helium transfer line will be necessary.

Since SRF structures should be compatible with CW-operation, the static load is an important issue as well as high Q_0 for CW operation, to minimize the cryogenic capacity. The cryomodule design should pay more attention to both aspects.

The Committee took note of the impressive progress made in improving the intrinsic cavity Q_0 and strongly supports this R&D program. The intrinsic Q_0 of niobium itself could be preserved but other surface contaminations may degrade it. A remaining key question is the risk of long-term degradation of Q_0.

In CW operation, gradient may need to be reduced due to one reason or another such as performance degradation, excessive cryogenic load, or shortage of RF power. Space for additional cryomodules needs to be preserved.

A series of prototyping efforts for SRF cavities and cryomodules are ongoing or scheduled. The achieved progress and results are impressive. The proposed SRF R&D deliverables for PIP-II will provide a strong basis for construction. There is a possible conflict of resources with other projects such as LCLS-II. The project team may need to prioritize the R&D items and allow some delay for the items that are not critical for the CD-3.

With the foreseen RF sources, Q_{ext} values can be optimized for pulsed operation. As a result, a good balance can be obtained between filling/decay time and beam loading assuming that 90% of the LFD is compensated by a fast piezo tuner. The corresponding Q_{ext} values are lower than the original values for CW by a factor of 2-3.

Lower Q_{ext} value will relax many control constraints. The reduction by 90% of the Lorentz Force Detuning using piezo-tuners is considered as challenging goal in operation. The Committee recommends continuing the R&D efforts on operational aspects and reliability.

Recommendations

R2: Get confirmation that the physics needs for continuous beam are essential in the long-term future.

R12: If resources are short, the construction of an SSR2 prototype could be delayed as well as the construction of the 6 cavity high beta cryomodule.

Linac RF

Findings

Six types of RF power sources are planned for the PIP II linac:

- One 75 kW, 162.5 MHz amplifier for RFQ (to be delivered in March, 2014)
- 4 kW, 162.5 MHz amplifiers for 3 bunchers
- 7 kW, 162.5 MHz amplifiers for 8 HWRs (to be specified for procurement)
- 7 kW, 325 MHz solid-state amplifiers for 16 SSR1s (has been bench tested. Considering India as possible source)
- Over 17 kW, 325 MHz amplifiers for 36 SSR2s
- 60 kW, 650 MHz amplifiers for 54 elliptical cavities (magnetron sources are under development)

No challenge nor show stopper are found in the above list. The 162.5 MHz RFQ amplifier will be delivered in March, 2014 for the RFQ power test scheduled early 2015. The 7 kW, 325 MHz solid-state amplifier has been bench tested. India is considered as a possible source for the 325 MHz amplifiers. For the 650 MHz source, an alternative magnetron-based solution is under development. A 650 MHz, 30 kW CW IOT is already available. The Argonne test stand is utilized for the test of PXIE 162.5 MHz cold window and bellows. The Committee encourages the planned early provision of the test stand, in particular, for the coupler power test.

Comment

Pros and cons of possible solutions for pulsed RF power sources were not presented at this meeting. The choices made in the context of Project X should be reconsidered, taking into account the low duty cycle operation of the PIP-II linac. Moreover, the conversion efficiency from wall plug power to RF should be given higher priorities nowadays than before, considering the recent prevailing public concern and the rising cost of electricity. The early provision of RF power sources is very important in order to serve test stands of various high-power RF components such as the input couplers as encouraged above. Needless to say, it is ideal and in most cases it is planned that the RF power sources thus provided can be the prototypes and the test stands themselves serve as their own tests. However, when the designed duty factor is drastically changed, the RF source choices are worth reconsidering.

The choices of RF power sources should be reconsidered for the low duty factor operation foreseen with PIP-II. Conversion efficiency from wall plug to RF is worth a special attention. The Committee considers that a review by a panel of RF experts would be appropriate before the final decision making.

Ring RF

For the MI, two options were presented for the required upgrade of the RF system. The first option is to operate the current RF cavities with two power tubes instead of one in a push-pull configuration. Obviously, this requires doubling the number of power supplies and solid state drivers. The second option is to use a more powerful power tube (EIMAC 4CW250,000B). This needs new mounting configuration (much longer tube), and new power supplies and upgraded PA cooling. The cost of the first option seems lower because the additional tube and its power supply are half as powerful. Other factors (reliability, maintainability…) need also to be considered for the final decision.

LLRF

Findings

The main challenge in the linac LLRF system is the Lorentz Force Detuning (LFD) compensation required when operating the Linac in pulsed mode. The present assumption is that the piezo tuner will reproducibly compensate 90 % of the LFD. Some simulation results have been presented, showing the necessity of feed forward (or learning algorithm) based upon the preceding pulse result.

The optimization of the external Q was attempted with an assumption of 20-Hz microphonic amplitude. The final external Q optimization may be done with waveguide iris and/or stub tuners.

Comments

In general, the external Q can be increased by external means. Careful study is necessary to define the possible range of adjustment.

A back up scenario should be established for the case that the piezo tuning fails, in particular, if the piezo tuning system is inside a cryomodule. The obvious option is to plan for tolerating an idle faulty system.

Recommendation

R3: Plan for injecting slightly below 800 MeV to be able to compensate for a faulty cavity.

Beam instrumentation

Findings

Adequate beam instrumentation in the Booster/RR/MI rings is essential for the progress of studies towards reaching the higher average and instantaneous beam intensities foreseen after PIP-II.

A large variety of instruments are needed for PIP-II. The development of the linac devices is part of the PXIE project.

In the LEBT, an Allison emittance scanner and some beam current monitors are planned. The Allison scanner utilized for CW operation is developed in collaboration with SNS and final fabrication is expected in March.

In the MEBT, many kinds of diagnostics such as transverse position, bunch phase, beam current, etc. are planned to be implemented. Warm and cold BPM pickups are in the prototype stage.

Several new non-intercepting instruments are proposed or considered: Ionization profile monitors and Electron wire profile monitors. Mode-locked psec laser "wire" for measuring both transverse and longitudinal profiles, are under development.

Observations

The higher the beam intensity, the more important the innovative diagnostics developed in PXIE will be. They may however not be needed during PIP-II where the intensity downstream of the chopper system is only 20 μA.

Only a few full time staff members are assigned to beam instrumentation. Accurate and dependable beam instrumentation is essential for characterizing beam in all accelerators.

Recommendation

R8: Make sure that beam instrumentation is adequate for supporting investigations and studies in the existing accelerators.

R11: Priority in the development of Linac beam instrumentations should result from an analysis of the needs of PIP-II at injection in the Booster.

Appendix1:

Charter of the
Proton Improvement Plan II, Machine Advisory Committee (XMAC)

The PIP-II Machine Advisory Committee (XMAC) is formed initially to review, monitor, and offer advice relative to the R&D program directed toward the development and preparation for construction of PIP-II, a multi-MW proton facility at Fermilab. The XMAC will continue in this advisory role once PIP-II enters the construction phase. The XMAC will be asked to look at the overall strategy and to concentrate on R&D areas that are deemed critical to successful implementation of PIP-II, and to offer advice and recommendations on the appropriateness of the associated effort. The XMAC is also invited, on its own initiative, to identify areas that need greater attention than is currently being given.

The XMAC will normally meet at least once a year, but may be called upon more frequently as conditions warrant. A specific charge for each meeting will be developed by the Fermilab Associate Laboratory Director for Accelerators and transmitted to the XMAC chair and PIP-II management team well in advance of the scheduled meeting.

The XMAC will be formally constituted as a sub-committee of the Fermilab Accelerator Advisory Committee (AAC) and the XMAC Chair will serve as a member of the AAC. This will allow integration of advice relative to PIP-II into the overall accelerator development strategy of the laboratory. The AAC reports to the Fermilab Director.

It is expected that the XMAC will present a verbal report at the end of each meeting, followed by a written report submitted to the Fermilab Director within one month. Copies of the report will be made available to the PIP-II management team and to the Department of Energy/Office of High Energy Physics.

XMAC members are appointed by the Fermilab Director with an initial term of four years.

Appendix 2:

Charge for the PIP-II Machine Advisory Committee (XMAC)

February 25-27, 2014
Fermilab

In the last six months the mid-term (5-10 year) plan for the Fermilab accelerator complex has evolved to a concept known as the Proton Improvement Plan II. This concept, derived from the Project X Reference Design, calls for a ~800 MeV pulsed superconducting linear accelerator (SCL) to replace the existing 400 MeV linac. The SCL will inject into the existing booster synchrotron to allow delivery of 1.2 MW of beam power from the Main Injector (at 120 GeV) for a long baseline neutrino experimental program.

The XMAC is asked to review the plans for PIP-II, including the design concept, the R&D plan, the project cost and schedule and the plan to prepare for construction.

Advice and/or recommendations are sought relative to the viability of the design concept and the appropriateness of the accompanying R&D strategy. In particular we would like specific advice, recommendations, and/or commentary on:

1. **Design Concept:** Does the PIP-II conceptual design represent a viable concept for a high intensity proton facility meeting the enumerated performance goals?

2. **Risks:** Have the primary areas of technical and cost risk associated with the design concept been identified?

3. **R&D Plan:** Is the R&D plan properly directed at addressing the identified risks in an effective manner? Are the risks appropriately prioritized and will the completion of the R&D plan provide a basis for proceeding to the construction phase with confidence that performance goals can be met?

4. **Plan to prepare for construction:** To what extent are the deliverables of the R&D plan necessary to complete prior to construction? Can or should some elements of the plan be carried out in the construction phase? If available resources do not support the complete pre-construction plan, which elements should be considered highest priority for available funding?

The XMAC is not limited by these specific charge areas and may delve into other related areas, and offer advice, comment, or recommendations, as it deems appropriate under the general guidance of this charge. We request an oral closeout presentation by the XMAC with Fermilab management, the PIP-II Collaboration, and DOE observer(s) at the end of the meeting. A written report is requested to be submitted to the Fermilab Director by March 14, 2014.

Appendix 3:
Meeting Agenda

https://indico.fnal.gov/conferenceDisplay.py?confId=7949
Access key: pip2014

Tuesday 25 February 2014

Executive Session - Comitium (08:00-08:30)
- Conveners: Dr. Henderson, Stuart

Overview and Description of the PIP-II Design Concept - Comitium

08:30 [0] PIP-II Overview: Goals, Status and Strategy HOLMES, Stephen
08:55 [1] PIP-I Overview: Goals, Status and Schedule Dr. ZWASKA, Bob
09:15 [2] 800 MeV Linac: Design Overview Dr. LEBEDEV, Valeri
09:35 [3] 800 MeV Linac: Accelerating Structures & RF Sources Dr. LEBEDEV, Valeri
09:55 [4] DISCUSSION
10:10 Coffee Break
10:25 [5] 800 MeV Linac: Warm Front End PROST, Lionel
10:45 [6] 800 MeV Linac: Cryogenic Systems KLEBANER, Arkadiy
11:05 [7] Booster Upgrades: Overview Dr. TAN, Cheng-Yang
11:25 [8] MI/RR Upgrades: Overview Dr. KOURBANIS, Ioanis
11:45 [9] DISCUSSION

12:00 WORKING LUNCH

13:00 [10] TOUR - CMTF
14:00 [11] Conventional Facilities/Siting Mr. HUNT, Jonathan
14:20 [12] Accelerator Facility Design: Safety and Radiation Shielding LEVELING, Anthony
14:35 [13] DISCUSSION

Coffee Break - (14:55-15:10)

R Program - Comitium

15:10 [14] Front End: PXIE SHEMYAKIN, Alexander
15:40 [15] Accelerator Facility Design: Machine Protection WARNER, Arden
15:55 [16] RFQ Status Dr. LI, Derun
16:15 [17] HWR Status Dr. OSTROUMOV, Peter
16:35 [18] DISCUSSION

Executive Session - Comitium (17:00-18:30)

Wednesday 26 February 2014

R Program (continued) - Comitium

08:30 [19] Superconducting RF YAKOVLEV, Vyacheslav
09:00 [20] RF Sources Mr. PASQUINELLI, Ralph
09:15 [21] LLRF Mr. CHASE, Brian
09:35 [22] Instrumentation SCARPINE, Vic
09:50 [23] DISCUSSION

Organization and Transition to Construction – Comitium

10:25 [24] Plan to CD-3 HOLMES, Stephen
10:55 [25] International Collaboration Dr. MISHRA, Shekhar
11:15 [26] DISCUSSION

Executive Session: Follow-up questions/discussions as requested by the Committee
Comitium (13:00-14:00)

Executive Session - Comitium (14:00-18:00)

Thursday 27 February 2014

Executive session and closeout - Comitium

08:30 [27] Executive Session
10:00 Coffee Break
10:15 [31] Executive Session
12:00 Working Lunch
13:00 [28] Closeout