Special MPP on LINAC4 Machine Protection

Participants: A. Apollonio, B. Puccio, Jan Uythoven, M. Deile, S. Gabourin, Y. Nie, D. Nisbet, A. Lombardi, B. Mikulec, M. O' Neil, N. Voumard, G. Hagmann, J-C Santamaria, D. Glenat, J-L Sanchez Alvarez, C. Martin, L. Arnaudon, F. Lenardon, M. Valette, M. Zerlauth.

The slides of all presentations can be found on the website of the Machine Protection Panel:
http://lhc-mpwg.web.cern.ch/lhc-mpwg/

1.1 Welcome and goals of review (D. Nisbet & M. Zerlauth)

- Most equipment systems deployed for LINAC4 are nearing completion; this special meeting is dedicated to review the readiness and implications of the machine protection aspects.
- The aim of today's meeting is not only to assess the readiness of connectivity to the Linac4 Beam Interlock system, and the availability of users for the 160 MeV commissioning and Half Sector Test (HST).
- Depending on the equipment systems, interlocks function are either still not fully defined or simply not implemented. The more we are nearing completion of the machine (and high intensity beams), the urgency for completing these tasks increases.
- Especially in view of a meaningful half sector test and the reliability run, efforts should be made to finalise system functionality as well as the integration into the global accelerator controls and protection architecture as much as possible.
- Links to Indico pages of meetings on the previous steps of the commissioning:
    - 50MeV Commissioning Preparation
        - https://indico.cern.ch/event/404834/
    - 50 MeV Commissioning Experience
        - https://indico.cern.ch/event/447582/
    - 100MeV Commissioning Preparation
        - https://indico.cern.ch/event/507450/

1.2 160MeV commissioning and reliability run plans (A. Lombardi & M. Vretenar)

- A quick review on the parameters of Linac4 was given, highlighting the 70 mA peak current to surpass the beam power provided by Linac2. Nominal current of 70 mA will however not be reached at first, but only two thirds of this value seem within reach.
- The machine is designed for 400 µs long pulses, for commissioning purposes pulses of max 100 µs will be used.
- All RF modules are now installed as well as the RF power supplies.

- The beam has been accelerated up to the CCDTLs and 100 MeV energy have been achieved during the last commissioning step with a temporary diagnostics bench.
- All the diagnostics are now nominal for the 160 MeV part of the line.
- During the commissioning up to 12 MeV of energy, direct measurements of emittance and dispersion were performed. From now on, non-interceptive measurements and the online operational diagnostics will be used.
- A lot of time and efforts were spent refining the numerical models. This and a good reproducibility of measurement with respect to simulations now allows to know where the beam is lost.
- Longitudinal parameters, amplitude and phase of the 23 RF structures currently have to be set by:
    - Observation of the beam loading.
    - Time of flight measurements, reconstructing the energy as a function of the phase of the cavity.
    - Transmission through a RF bucket.
    - Reconstruction of longitudinal emittance.

All these measurements are safe and can be done at low current, require however the masking of RF cavities which are not in operation. Non-persisted setting in the RF FSA classes represent a major issue as after power-cuts or FEC reboots the settings have to be re-established.

R1: Persist RF settings as soon as possible in order to avoid the repetitive need of re-setting up the machine/tuning.

- To set the phase of a cavity we have to observe the beam in the following structures.
- After 30 MeV all the beam can be transported to the dump without losses even if the cavities are off.
- Up to 60% of the beam is lost when scanning the phase of DTL1. When the bunchers are on, there is a large plateau at 100% transmission.
    - Markus asked how often does the phase of the DTL1 need to be set.
    - For the majority of cases, the phase will not be scanned through 360 degrees every time, but only a fine-tuning will be needed. When losing RF power on this structure, the phase will be swept.
    - Bettina added that the watchdog threshold could be changed to cut the beam if this happens.
- In the bending magnets (bring the beam from L4 to the L4TL), the second dipole has a large aperture to accept a Y chamber, originally meant for emittance measurements by laser stripping. For a limited amount of time, this Y-chamber may be used to install a medical experiment. In the context of studies for linear accelerators for medical applications carried out at CERN, it was asked to put a water chamber to observe braking of the beam.
    - Jan asked how this will it fit in with the normal operation of the Injector complex.

  - Markus answered it is a special setup that will be used only for a limited amount of time; parallel use with beam to PSB is excluded.
  - David added the timeline for this is post half-sector test, but certainly before any nominal operation of Linac4.
- Reliability run: once the half sector test and the 160 MeV commissioning is completed, Linac4 will be run in a quasi-operation mode, dumping the beam onto the dump while tracking availability (the observables for this still remain to be defined). A simple way would be to log the current before the dump. Discussion are ongoing with Andrea to implement the accelerator fault tracker for Linac4.
- During the beginning of operations there will be a lot of childhood faults to be expected. The current commissioning team does not have much expertise in the domain of availability so help is needed there.
- Planning:
    - Mid-Sept to mid-Nov commissioning to 160 MeV
    - Mid-Oct to end Feb 2017 half sector test
    - Reliability run, probably in 2 phases
  - David commented that many groups are operating in the control room with still incomplete systems. Also goals have to be defined in terms of availability for Linac4, especially as Linac2 is currently operating very reliably. A primary goal would be to achieve Linac2.
  - Jan proposed to reserve a period of a few weeks where people don't perform any modifications and run while tracking all faults, allow for a period of upgrades and changes, and run stably for another few weeks without touching anything.
  - Markus asked how the reliability run would be organised; as continuous observation is required, one might need some people in the CCC to reset and run things in an efficient and meaningful way.
  - Alessandra commented the project does not have a team of operators assigned yet.
  - Bettina added it requires additional work on the PSB operations side and it hasn't been discussed yet.
  - Alessandra concluded there will most likely be two reliability runs.

R2: Measurement for time of flight for RF requires RF cavities partially switched off but not interlocked into BIS. Losses of up to 60% are possible in such cases. A clear operational procedure (including beam parameters) should be established how to mask the relevant RF cavities while still allowing for safe measurements.

1.3 Half-sector test: Planning, objectives and operations (B. Mikulec)

- In nominal configuration, the future Linac4 beam will be injected in the PSB and stripped, there is a H0 and H- dump to intercept the 2% of beam that is not stripped by the foil. This is a very compact layout because there is no space in the booster for an external dump, this is why there is an internal dump for unstripped species. The foil handling systems allows to exchange foils and for a screen to be installed instead of the foil to measure beam position.

- In addition, a permanent installation after the PiMS with a foil and a BTV will be realised and primarily used as test setup of stripping foils.

- Test program for the foil in front of the Linac4 dump: lifetime of foils and holders, test of controls, estimate of stripping efficiency, detection of foil breakage. These tests can be done in parallel of LINAC4 operation as long as the appropriate interlock logic is set, i.e. only to allow insertion of the foil if the destination equals the Linac4 dump.
    - Chiara would also like some destructive tests with higher current.
- The HST (half-sector test) specific implementation, will feature half of the PSB injection chicane, a testing foil and an external dump with BCTs and Beam diagnostics. The girder with all relevant equipment was lowered in the tunnel on Wednesday, only the lateral shielding is missing, the alignment has been completed shortly afterwards.
- The test program for the HST: stripping foil, dedicated H^0/H^- current measurements, dBLMs to measure secondaries near the H^0/H^- dump, tests with a thick foil to have no unstripped species and check the loss of beam. A large fraction of the interlocks foreseen for the HST will be kept in the final PSB implementation of the BIS, nevertheless some inputs have been added specifically for the HST.
- Original plan of HST, 2 months with lower current and two months with higher current, in the last part the power of Linac4 will be too high, and the shortening of the pulses with the chopper will be needed.
    - David asked whether there would be a vast span of settings and they will be changed very often?
    - Bettina answered there would only be two consecutive ones.
- A new interface aiming at defining and tracking all commissioning tests OP would like to perform was implemented. The progress bars for the different tests can be seen on the website.
- Planning: the installation should be finished early August, equipment tests will take place in August, and the cold checkout is planned for September in order not to interfere with the 160 MeV commissioning. Tests with shortened pulses in October/November and increased power in December.
- Many issues have been identified during fabrication and installation, which will help to avoid delays for the final PSB installation; all equipment groups were pushed to finalize controls and applications.
- Links to some documentation:
        - HST Twiki website
        - Indico
    - C. Martin asked if there was a dedicated BIS signal to guarantee the integrity of the foil.
        - No, this interlock is internally handled, only the foil position will be interlocked as well as a beam transmission watchdog.
    - Bettina said the dedicated cycle for HST will be included in the 4-cycle super-cycle.

- Markus asked how quickly the bending magnets can be ramped up and down.
  - D. Nisbet replied with about 1 Hz.

R3: Clarify the interlocking of BSW3/4 magnets, H0/H- dump and current monitor (all connected to PSB BIS).

1.4 Machine Protection configuration for 160MeV (A. Apollonio)

- The machine is reaching its final configuration so we should equally approach the final configuration of the machine protection systems, including the BIS and all relevant MP inputs which are mandatory for the 160MeV phase. Nevertheless, the BIS should allow performing all required actions and allowing the needed flexibility to allow for efficient commissioning.
- In view of the 160 MeV commissioning and the HST two additional BICs were added (the transfer line and L4Z) with respect to the 100 MeV commissioning. The configuration is almost final, just missing the PSB as a (final) destination. The source BIS is in its final configuration already, the L4 one is almost final with the RF still being connected to a maskable input. A long term decision should be taken for the RF input, whether this will be kept maskable or whether it should become an unmaskable input as originally foreseen.
- Inside the truth table of the source Master BIC, the source internal and HV signals do not yet have their final user logic implemented (and therefore masked/disabled), the chopper quads have a wide threshold, the Low energy watchdog logic has to be changed to take into account the new BCT position, the RFQ does not include the LLRF part yet and the CCC operator veto is not present.
- For the slave Linac4 BIC, the “external conditions” is forced to true (as not necessary until the final connection to the PSB) and BLM thresholds have to be hardcoded. It should be discussed what values should be set for this, as no experience exists yet for Linac4 BLMs and expected losses.
- The input “Linac4 Foil out” will be necessary for injection into the HST and the PSB to avoid H- being stripped and entering the bending magnets at the end of the Linac4.
- As usual, the EDMS document was updated for the commissioning steps of the BIS.
- Conclusion: approaching the final configuration with the 160MeV commissioning and the HST, 2 additional slave BICs will be installed.
  - The question was raised how to achieve a sufficiently long pulse length to approach the limits for a destructive test of the foil test-bed
    - This might require changes of settings of the (pre-)chopper or the BIS inputs.
  - Markus asked if all of the additional inputs for the 160 MeV phase and HST are already available and connected?
    - C. Martin answered they are all reserved, however cables remain to be pulled and the CIBUs needs to be installed in the client rack.

- Alessandra commented that for the next phase the RF interlock needs to be maskable. She asked if it is possible to interlock so one can't turn on the bending magnets if the RF is off to avoid injection with wrong energy.
  - Markus asked how will the masking be handled for later (standard) operations.
  - C Martin answered that Linac4 currently does not have a concept of Setup beam flag, hence mask-able channels may remain masked for longer durations. Mask can be removed by software but in general it will be the responsibility of the operations crews to remove the masks if not needed anymore.
- Markus asked if one could think of a way to remove the masks when changing users.
  - C. Martin answered the software is maybe not reliable enough to do perform this action
- Bettina concluded maybe a regular check, e.g. once a day, can remove the masks on interlocks.

R4: Investigate the possibility of implementing a concept of Setup beam intensity to be defined for future (standard) operation? A software process (e.g. SIS) could remove all masks if a certain intensity is exceeded (without the need of a dedicated SMP system)?

R5: Clarify whether the RF input should be kept maskable in the long term or if masking of individual cavities can be done in a sufficiently transparent way inside the RF system?

R6: Investigate the possibility and usefulness of including an RF signal as as user Permit in the L4T BIS to avoid extracting beam into the L4T if we are not at the correct energy.

1.5 Linac4 source: Status and interlock logic (M. O'Neil)

- The source hasn't changed much in terms of interlocking since the last review.
- The source is stopped by cutting its HV RF. The relevant conditions are HV, internal and startup, they are not reported to the BIS user permit yet, but only generate a general source interlock.
- Source startup allows conditioning of the source to allow running if the stopper is in 'IN' position, even if downstream equipment is not available. If the beam stopper is out, internal and external conditions have to be true.
- In summary, there have been no changes since last commissioning phase and no changes are foreseen.
  - David asked if the interlock is only monitoring the HV voltage now or does it consider the Einzel lens in the extraction system?
    - No, there are now only three pulsed power supplies for the extraction system (and no longer a DC system). Since the Einzel lens can now go to higher voltages, the thresholds need to be verified.
  - Markus asked about the internal interlocks.

        - When finalized, it will stop the gas injection, and to avoid damaging the source by injecting RF without the gas, it will stop the RF power.
    - David commented the source is not providing too much information to the BIS, which is good for availability. Damage to the rest of the machine is unlikely (e.g. RFQ) but has to be verified.
    - Markus added it would be good to verify that the HV thresholds (currently mitigated by an additional SIS implementation) are in the appropriate range.
    - Alessandra answered the only risk now is to extract with lower energy, in the past it was a big power supply with a capacitor and it could ramp up (voltage-wise), the beam would thus end up at the wrong place in the dump and with higher energy.

R7: Verify the correctness and functionality of the SIS interlock tree before the 160MeV commissioning stage.

1.6 Pre-Chopper: Status and interlock logic (N. Voumar)

- The pre-chopper uses a pulsed electric field to deflect the 95 keV beam from the RFQ when it is not required. It also cuts out the beam from the source rise time and tail. It features 2 µs to rise/fall, 2% stability at top voltage and +/-10V precision at zero voltage.
- Four timing signals are transmitted, start and stop for tail and rise clipping. The pre-chopper is the target of two beam permit signals, source and chopper. The driver provides a user permit to the BIS, the included conditions are: external, over-voltage, capacitor-voltage, timing signals sequence (verifying the consistency of the order of the four signals).
- An analogue measurement of the voltage applied between the plates during the pulse was added and can detect a fault within the pulse.
- All interlock functionalities have been implemented and validated in 2013, and tested during the BIS commissioning in 2015.
    - Markus stated there is no need to change anything. He asked if any special test related to the HST should be done (also as the interlock logic was last tested three years ago and some settings changed, thus it might be a good idea to revalidate the most critical parts.

R8: In view of the importance of the pre-chopper, revalidate the interlock functionality (last done in 2013), with an emphasis on the added functionality related to the ppm functionality and timing dependence of the pre-chopper (i.e. investigate behaviour of pre-chopper in absence or misconfiguration of timing events).

S1: The electronics receiving and processing the BEAM_PERMIT from the BIS is a critical piece of the interlock functionality for LINAC4 and should adhere to quality constraints required for an operational machine in the LHC injector complex.

1.7 Chopper: Status and interlock logic (G. Hagmann)

- The chopper is made of two modules (Chopper Trigger Unit – CTU, Chopper Drive Unit – CDU), the pattern is created in the trigger unit, and the drive unit is connected to the BIS. These systems are at two different locations, one in the faraday cage and the other in the Chopper amplifier racks .
- Status: the simulated PSB timing were tested with the help of the timing team; it will not change on the RF low level side after the booster is connected. The chopper power unit was installed and tested with beam in June.
- Still missing: 1 interlock between the two modules, 1 interlock from the Chopper plates monitoring. An upgrade after the start of the 160 MeV commissioning is foreseen.
- Upgrades: Two chopping pattern types are now possible, a simple periodic chopping pattern or an advanced chopping pattern where the chopper can be controlled with a resolution of 1 RF period needed for longitudinal painting. The periodic chopping pattern settings are available in the working set, the complex chopping pattern needs higher level application to be designed. The chopping pattern is played between the ring start and stop timing pulses. Four dedicated inhibits, if one ring is not ready one can chop the beam in Linac4. Ring blanking is now available, if the sequence has to skip a ring, the next one will be advanced so the cycle is shorter.
- Status: the final HW of the Chopper Trigger Unit is installed, ring blanking and ring inhibits are ready.
- To be done: complex chopping patterns, re-commissioning to the dedicated BIS. Internal checks: vacuum and power amplifier state.
    - Beam permit was commissioned in 2015, this is an asynchronous interlock for the chopper, when the beam permit is lost, the rest of the cycle is chopped, without impact on the user permit. The user permit is also asynchronous and latched, needs an OP action to re-enable operation.
    - The list of errors is not complete, the sources of interlocks description has to be done, as well as the validation procedure. Software error and pulse and chopper plate error monitoring are not implemented yet.
- The Chopper Drive Unit prototype is installed and final hardware is being tested in the lab.
- This schedule is optimistic because an action on the FESA class is necessary, we would need to run with the prototype and final version in parallel for some time.
- Chopper plate monitoring will be only available in autumn, at the earliest.
- Interlocking between the two modules (timing and drive) is not done.
- A strategy for recommissioning the BIS has to be defined, e.g. for the piquet.
    - David commented this recommissioning will take some time and schedule might be negotiated with Alessandra.
    - G. Hagmann said some features will not be available for the HST.
    - Markus added the capability of making short pulses is available, which is one of the primary requirements of the HST, even if it will be hardcoded at first.

- Alessandra stated the worry is that if the chopper fails one would get a whole pulse from the source.
- Markus concluded a large portion of the tests mentioned can be done before the HST. It would be good to validate the system behaviour in case of missing/misaligned timing events.

R9: As for pre-chopper, the reliable chopping of the beam pulse to the short durations required for the initial 160 MeV commissioning and HST should be assured and eventual mitigation measures defined (in absence of the chopper monitoring system). System behaviour in case of missing/misaligned timing events needs to be tested.

1.8 Watch dogs: Configurations and interlock logic (J. Santamaria)

- As of now two TRICS cards are sending the BCT signal to the FESA class which holds the logic, the watchdog (WD) cards relay the processed signals to the BIS.
- A third CIBU module has to be installed. The WD FESA classes are operational.
- The low energy WD compares current from the LEBT to after the RFQ.
  - One of the BCTs was moved, the logic needs to be changed to allow for more maximum current.
- The high energy WD compares current in front of the DTL and before the dump.
- Installation of 3 more BCTs are pending, the two used for the HST and the L4 transfer-line one.
- The WDs for the booster are ready for installation.
  - David asked who is in charge of setting the threshold for the WDs? Is there experience from e.g. Linac2 one could benefit from?
    - It is now set by the user, respectively the commissioning team, including resets in case a watchdog threshold has been exceeded resulting in a latched USER_PERMIT.
  - Markus concluded it would be good that the operators get hands on experience with this tool.

R10: Define and document WD logic and thresholds for the 160 MeV commissioning and HST.

1.9 L4 Power converters and switching magnet acquisition cards: Configurations and interlock logic (D. Nisbet)

- The permit is given when the current is inside a certain window. There are two threshold windows per system.
- There are 4 PC BIS interfaces: source HV (not active), quads (the current threshold 20-200A is very wide), MB dump (0±18A), MB transfer line (590±18A).
- The final settings have never been specified in a document yet.
- The quad threshold is set to the full operating range, which was done for flexibility of operations, the settings now have to be changed locally.
- For the source a 5% variation to nominal tension will be tolerated.

- In the final implementation, the logic will be done in a decode card, we will go for a full software interlock.
- The BIS interface for quads is ready, the MB case might be ready in September.
- The HV PC interlock will be available in 2017.

1.10 Beam Loss Monitors and Diamond detectors: Configurations and interlock logic (C. Zamantzas)

- The laser emittance meter consists of 2 laser stations with corresponding dBLM, before and after the first bending magnet.
- For diamond 3 and 4 (second system) there is no need for an interlock, because the two first MBs are powered in series, beam can only reach this destination if the bending current is correct.
- For diamond 1 and 2 a fast HW interlock on the MB current is needed if the diamonds are in 'IN' position because the diamonds cannot stand a single Linac4 pulse.
- The system is not installed yet, but the interlock is not needed for the HST.
- The acquisition electronics are under development. The implementation of the emittance meter is foreseen mid-2017.
    - Markus questioned the need to monitor the MB current from the emittance meter because the BIS is already performing this task. It could just be a position switch checking the position of the diamonds and the BIS would ensure to inhibit the respective beam destination in case conditions are not met.
    - In a follow-up meeting, it was agreed to add one input to the L4Z BIC, checking that the position of the detectors is OUT (input name 'BMLEM OUT'). The destination L4Z will be inhibited if the detectors are IN.

R11: Implement and document the additional BIS channel and updated BIS matrix for the protection of the laser and diamond detectors.

- About the BLMs, 3 monitors are waiting for connectors and 5 are missing drilling holes or installation. The dBLM will be moved before the BCT.
- For the HST, 2 detectors will be installed between the first bend and the girder, one IC and one diamond which lacks the support pole which was supposed to be installed. The electronics are ready and installed, the cards are well known on the LHC side. During initial validation tests, the BLM signal seemed to be moving along the 100us pulse. A better grounding of the support was requested.
- Interlock functionalities: thresholds remote driving to FPGA, the absolute threshold values are missing and need to be defined. Does operation start without or with maximum thresholds and will a second CIBU be needed?
- To be done: cold functionalities commissioning, manually generate signals and check interlock response.
    - Markus asked if it is possible to set different thresholds for different users?

        - It is, but only for the software interlock, not the HW path.
    - Andrea asked, since the monitors were installed during the 100 MeV commissioning, if some data was recorded.
        - The BLMs were there but not powered, a lot of data can be generated with beam based measurement.
    - Markus commented there are no models for the Linac4 yet but it would be a good exercise for the BLMTWG to help defining the required threshold sets for later operation.
        - Anton answered everything is different from the LHC, detectors and electronics, it might not be ready in two months' time.
    - Markus concluded one should go for experienced based thresholds.

R12: Empirically define a first set of reasonable BLM thresholds during first beam setup, involve BLMTWG for definition for future operational thresholds.

1.11 L4 RF system: Status and interlock logic (D. Glenat)

- There are 17 klystron plugged on cavities, the RFQ and the bunchers.
- The PLC serves as interface for the CIBU and the BIS.
- In the PLC there are 4 cards, module 0 for all faults, module 1 for HV faults, the relays for all the other systems are connected by an AND in a 1oo2 logic. If one redundant channel fails, the BIS USER_PERMIT is triggered.
    - C. Martin commented the goal of the CIBU is redundancy, he doesn't think there are two truly redundant channels available.
        - If one channel stops the permit, the other one will also stop a little later.
- The BIS settings are different for DTL 3, 4 and 5, they can only be changed by an RF expert by modifying the 'interlock matrix' inside the PLC.
- A control screen will be set for local or remote control, to be discussed.
    - Bettina asked if the interlocks can be masked for the 160 MeV commissioning. Indeed, cavities can be individually masked in the logic to the BIS, such masks are visible on the RF expert screen (only).
    - Alessandra added one can have 50 MeV beam in the machine with all the other cavities off (as the beam will impact on the dump this is not a major MP concern); such masking is beneficial but needs to be visible to the operators.
    - Markus answered the straps are applied on the output that combines all cavities together.
    - Alessandra reacted that one can't know if the energy is not right without the bending because the transmission to the dump is close to 100% once the beam reaches 30 MeV, one will see it in the BLMs in the bending magnet but not identify it from the current on the dump.
    - David added that all modules will be necessary for the next phase.
        - All modules having passed the DSO tests can go in operations.
    - David concluded we now have to check the masked status of interlocks in all systems, we need a very visible and readable interface (see R5)

1.12 L4 VAC system: Status and interlock logic (J. De la Gama) – MPP meeting on 26th of August

- The VAC system provides 4 different interlocks, one of which is used for the BIS USER_PERMIT. IF a single valve is closing the USER_PERMIT is forced to FALSE.
- LINAC4 valves are based on LHC interlock system. A valve is closed and the interlock is triggered if 3oo4 of the devices trigger.
- The USER_PERMIT includes the trigger signal as well as the end switch position of the valve in order to provide a USER_PERMIT=FALSE state as long as valves are closed or in the process of closing.
- Masking of valves which were not yet installed or operational is done in a 'HW chassis/matrix' using dummy connections for not yet installed devices.
- The synoptic already provides the overview of the full final system

AOB – Wrap up

- All the open questions will be integrated to the minutes and an offline follow up will be done in preparation of the L4 connection readiness review on the 30th of August.
- Markus concluded that it was very useful to have this preparatory meeting and thanked all participants and especially the speakers for their preparation work and the open discussions.

R13: The prior recommendations and MP related (re-)commissioning tests should be included and tracked as part of the commissioning plan currently drawn up by the operation crews for the HST. As a general remark, PSB operations should get increasingly involved in the commissioning and operation of L4 to provide crucial feedback on current tools and eventual missing functionality and SW components.