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the
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project

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Feasibility Study

PS BOOSTER ENERGY UPGRADE FEASIBILITY STUDY

Abstract

This document summarises a survey of the CERN PS Booster systems with regard to a possible energy upgrade to 2 GeV. Technical solutions are proposed along with a preliminary estimate of the required resources and the time lines.

Prepared by:	***Checked by:***	***Approved by:***
Klaus Hanke BE/OP klaus.hanke@cern.ch **Thomas Hermanns** **Giovanni Rumolo** **Davide Tommasini** **Antony Newborough** **Marco Buzio** **Alan Findlay** **Mauro Paolouzzi** **Oliver Aberle** **Serge Pittet** **Edgar Mahner** **Jocelyn Tan** **Bettina Mikulec** **Jan Borburgh** **Leandro Fernandez** **Davide Bozzini** **Slawomir Olek** **Mauro Nonis** **Thomas Otto** **Ingo Ruhl** **Tobias Dobers**	**Mike Lamont** **Oliver Bruning** **Lucio Rossi** **Edmond Ciapala** **Roberto Losito** **Jean-Paul Burnet** **Jose Miguel Jimenez** **Rhodri Jones** **Volker Mertens** **Eugenia Hatziangeli** **Francois Duval** **Safety, RP???** **Paul Collier** **Frederick Bordry** **Vincent Vuillemin** **Roberto Saban**	**Steve Myers**

Distribution List:

History of Changes

Rev. No.	***Date***	***Pages***	***Description of Changes***
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1. INTRODUCTION AND SCOPE OF THE DOCUMENT

As a follow-up of the Chamonix 2010 workshop [1], a study has been requested by the director of accelerators to investigate an increase in beam energy of the CERN PS Booster from presently 1.4 GeV to about 2.0 GeV. A task force has been put into place with the following mandate:

The aim of the study is to evaluate the technical feasibility of an increase in beam energy of the CERN PS Booster from presently 1.4 GeV to about 2 GeV as proposed at the Chamonix 2010 workshop.

The study comprises:

• Confirm the potential gain in terms of intensity and brilliance for LHC-type beams as presented at the Chamonix 2010 workshop.

• Confirm the technical feasibility. Identify accelerator components and equipment that need to be upgraded or exchanged. Identify potential showstoppers and point out solutions. Assign the responsible groups/units. Provide first rough time estimates for the various interventions needed.

• Provide a first estimate of material and personnel resources needed to complete the upgrade. Draft a project break-down into work packages, in preparation for a project to be launched by the director of accelerators.

A working group has been set up to evaluate the technical feasibility of such an upgrade covering the following areas:

1. Beam Dynamics (BE/ABP)
2. Magnets (TE/MSC)
3. Magnetic Measurements (TE/MSC)
4. RF System (BE/RF)
5. Beam Intercepting Devices (EN/STI)
6. Power Converters (TE/EPC)
7. Vacuum System (TE/VSC)
8. Instrumentation (BE/BI)
9. Commissioning and Operation (BE/OP)
10. Extraction, Transfer, PS Injection (TE/ABT)
11. Controls (BE/CO)
12. Electrical Systems (EN/EL)
13. Cooling and Ventilation (EN/CV)
14. Radioprotection and Safety (DGS/RP)
15. Transport and Handling (EN/HE)
16. Survey (BE/ABP)

Further to the above listed work units, representatives are involved in the working group for drawing office (EN/MME), consolidation (EN/MEF) and PS operation (BE/OP/PS). The study is closely interleaved with the consolidation program for operation of the PSB through the next 25 years.

This document summarises the conclusions of the working group reached between March 2010 and June 2010. Technical solutions are proposed along with a preliminary estimate of the required resources and the time lines. The document should serve as a basis for the decision making on a possible future project and it is the first step towards a technical design report to be edited subsequently.

A few points were clarified at an early stage of the study:

- The study does not comprise other upgrade options as e.g. faster cycling.
- The request was made put the energy increase into operation rather rapidly, if technically feasible before the commissioning of Linac4 in 2015. This would entail ramping the beams up from the present 50 MeV to 2 GeV, and furthermore that the upgrade would be put in place before completion of the Booster consolidation, notably the one of the RF system. We have preliminarily studied the consequences of running the PSB at 2 GeV with the present 50 MeV Linac2. In the course of the study it was found that the time lines are such that putting in place the energy upgrade before the commissioning of the PSB with Linac4 in 2015 is not feasible, and the option to run the PSB at 2 GeV with the present 50 MeV Linac2 was discarded.
- For the beams delivered to the PS we have studied the following scenarios:

  1.) All beams to the PS are executed at 2.0 GeV. Beams to ISOLDE will remain at the present 1.0/1.4 GeV. The Booster extraction must work in ppm mode between 1.0 and 2.0 GeV, but the BTP line (presently not ppm) does not need to be upgraded. In case of a major ISOLDE breakdown, it must be possible to direct all Booster cycles to the PS. Therefore all systems must be compatible with running every Booster cycle in a supercycle at 2.0 GeV.
  2.) Only LHC-type beams are executed at 2.0 GeV, all other beams remain at the present 1.4 GeV. LHC-type beams and other beams are executed in ppm mode, which requires an upgrade of the BTP line for ppm operation.
  3.) Only LHC-type beams are executed at 2.0 GeV, all other beams remain at the present 1.4 GeV. The BTP line is not upgraded. During periods when LHC-type beams are executed (LHC filling as well as setting up and optimisation in the injectors) the supercycle must be composed with a number of zero cycles in order to allow the BTP line magnets to change settings.

  The difference between scenarios 1.) and 2.) is purely a cost issue. In the course of the study it was found that the option to run LHC beams at 2 GeV in ppm mode with 1.4 GeV cycles does not reduce the cost of the energy upgrade, but leads even to a slight increase in cost.

  Scenario 3.) has been looked into and the loss of beam time for the non-LHC physics program estimated. The details are reported in the chapter “Commissioning and Operation”.

The following chapters address the various areas in more detail with regard to a survey of the equipment/system at 2 GeV, identification of critical issues and potential showstoppers and the technical solutions that are proposed to be put in place.

2. BEAM DYNAMICS

2.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

None at this stage.

2.1.1 CRITICAL ISSUES AND PROPOSED CURES

No critical beam dynamics issue is anticipated in the PSB with the 2 GeV operation.

However, for the PS to be able to digest an LHC25 beam at 2 GeV with doubled intensity, a few issues must be looked into in more detail:

1. Resistive wall head-tail instabilities at flat bottom, which could become up to 50% faster than presently. Linear coupling, octupoles and transverse feedback are potential cures.
2. TMCI at transition crossing. Extrapolating with a simple scaling law from the existing observations on the TOF beam, we expect a factor 2 margin that guarantees the stability of the double intensity LHC25 beam if it crosses transition with the γ-jump scheme.
3. Longitudinal coupled bunch instabilities during the ramp and at flat top. More studies are necessary to determine to what extent they may limit the future performance. A possible solution, which requires anyway a full study, is the installation of a broad band cavity to be used for longitudinal feedback.
4. Electron cloud and transverse instabilities at flat top. If the dependence of the instability onset on the bunch length versus intensity alone is confirmed, a double step bunch rotation can help (as opposed to the present adiabatic shortening followed by a fast compression).

2.1.2 FURTHER STUDIES NEEDED

To address all the above points in an exhaustive manner, we can envisage actions on both simulation studies and dedicated MDs:

- For point 1), a simulation study could be useful to confirm the expected decrease of rise time and assess the efficiency of the possible cures (i.e., how much linear coupling would be needed, how much octupole strength, how much gain/bandwidth of a transverse feedback system)
- To confirm the predicted margin of the instability at point 2), a simulation study for the LHC beam with doubled intensity at transition crossing will be carried out. The study is planned to become the natural closure of the current Ph.D. work on TOF [2].
- Point 3) is already listed as a subject with high priority among the RF MDs proposed in the 2010.
- We have written and plan to submit an MD proposal to carry out a detailed study of point 4). The proposal is found in the appendix. Our goal is to determine the nature and behaviour of the transverse instability, as well as its relation to the presence of electron cloud in the machine. In parallel, since we know that the electron cloud actually builds up in the PS with the LHC25 beam for bunch lengths below a certain threshold, it could be very helpful to carry out a simulation study of the beam stability against electron cloud, when the intensity is doubled.
- To allow the maximum flexibility in scanning parameters during the above proposed MDs, the first requirement is to assess the maximum intensity that can be presently produced in the PSB and sent to the PS for both the single and multi-bunch LHC beams. The present constraint on the transverse emittances (2.5 μm) can be relaxed (both because it turned out to be too conservative and secondly because it is better to inject into the PS with larger transverse emittances in order to compensate for the increased intensity and try to stay within the space charge limits at injection)

2.1.3 INPUT NEEDED FROM OTHER WORK PACKAGES

None at this stage.

2.2 TECHNICAL DESCRIPTION

MD proposals.

3. MAGNETS

3.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

Main Units

• Modeling of the magnets shows that the new field levels seem to be achievable. Initial magnetic measurements confirm the results of the models for the bending magnets. The saturation of the outer rings of the bending magnets will increase from around 1% to 5%. More detailed measurements are planned.

• The extent of the modifications to the cooling parameters is dependent on the RMS current of the magnet cycle. Different scenarios of the magnet cycle are being explored by TE/EPC.

• A concern over the life span of the magnets at 2 GeV operations has been raised.

Auxiliary ring magnets

• The majority of the auxiliary ring magnets is only used at injection energy and will not be affected by the upgrade to 2 GeV. The study for the remaining magnets used at ejection energy is still to be completed.

Transfer line magnets

• Initial study shows that the majority of the transfer line magnets will be ok for 2 GeV operations. This can only be confirmed when a complete study has been made for the optics.

• The magnet BT.BHZ.10 is currently being consolidated with a planned new spare to be built. Consideration is now being made for 2 GeV operation as is has already been stated by TE/EPC that the existing power supply would not be compatible with the existing magnet run at a higher current.

Study is still ongoing.

PS Injection Bumpers, Low Energy Correctors and Quadrupoles

• Further Study is needed

3.1.1 CRITICAL ISSUES AND PROPOSED CURES

Main unit cooling.

Scenario 3121 A RMS (Scale of today's magnet cycle)

The current magnet cooling parameters for the main units are not adequate. Initial calculations suggest that the pressure and flow must be almost doubled to maintain the same operational temperature of the magnets to that seen at 1.4 GeV if there are no modifications made to the cooling circuits. Although it may be possible to achieve these new values with an upgrade of the cooling station it would not be advisable to run the magnets at this higher pressure due to the design of the cooling circuits.

It has been stated that a trade off between an increase in pressure/flow and a higher operational working temperature could be acceptable; while this is generally true there is a risk that the life span of the magnets could be reduced at the higher temperature.

For the main bending magnets the proposed action would be to modify each of the magnets by connecting pairs of coils in parallel instead of than in series. This would keep the water pressure drop with an increased flow within reasonable limits. This action would require that each magnet is removed from the machine to be modified.

For the main quadrupole magnets the proposed action would be to install a new high pressure cooling circuit around the machine. This action would require a change of the flexible cooling circuits to rigid system. It may be possible to perform this action in the machine without removing the magnets. Further study is needed.

Scenario 2369 A RMS (faster pulse possible with POPS)

The increase in RMS current is relatively small compared to the 1.4 GeV cycle and no major modifications would need to be made to the magnet cooling circuits. Due to the higher voltage generated by a shorter ramp it would be beneficial to divide the machine in two and use two MPS as discussed with TE/EPC bringing the voltage seen by the magnets to a similar level to that of the 1.4 GeV operation. It is still to be seen if the magnet field can follow the faster current ramp.

Life span concerns

A concern has been raised over the ability of the bending magnets to withstand the forces of the coils against the retaining plates. Initial calculations show that although there is a substantial increase in force the absolute levels should be acceptable. If however after the calculations have been confirmed with measurements there is still a concern, the amount of shimming material between the coils and plates can be increased to compensate for the increase in force.

3.1.2 FURTHER STUDIES NEEDED

Main unit cooling – This will depend on the magnetic cycle.

Life span concerns – Testing of one of the spare main bending magnet is planned to confirm the calculated forces acting on the coil retaining plates. Testing is being planned at the nominal current, upgrade current and up to nearly two times the upgrade current to prove the robustness of the assembly. Testing at the nominal current and upgrade current will be completed in b.867 while the test at two times the upgrade current can only be completed in SM18 due to the availability of a power supply.

Magnetic measurements – Further magnetic measurements are planned to confirm the field quality of the main units. Measurements will also be made to confirm that the magnets can followed the suggested cycles with respect to the eddy current effects.

3.1.3 INPUT NEEDED FROM OTHER WORK PACKAGES

The magnet cycles and parameters need to be determined.

3.2 TECHNICAL DESCRIPTION

Main Units

Main bending magnet cooling circuits – The worst case scenario is that each bending magnet has to be removed from the machine for the cooling circuits to be modified.

For the best case scenario the cost would be greatly reduced as the magnets would not need to be removed from the machine with only minor modification needed.

Main quadrupole magnet cooling circuit – The worst case scenario is that the cooling circuit of each quadrupole magnet is upgraded to a rigid system so that they could operate with a higher supply pressure.

For the best case scenario only minor modifications would be needed to the magnet circuits.

For the quadrupole magnets even with the best case scenario a more robust cooling system would still be recommended as part of a consolidation program somewhere between what is needed for an increase in supply pressure and where we are now.

Main Bending magnet shimming – If it is seen that the main bending magnets would need additional shimming material between the coils and retaining plates it may be possible to complete the work inside the machine.

Main bending magnet saturation – The bending magnets have already entered into saturation for the outer rings at 1.4 GeV operation. This effect is compensated with a 30 amp trim power supply connected to the outer rings. At 2 GeV operation it has been shown through modelling and measurements that the amount of saturation will increase further and if the same approach is taken to compensate for the saturation then a trim supply of around 300 amps will be needed. Dividing the circuit in two as suggested by TE/EPC would remove the need for this supply as the two MPS could be run at different currents, however the total RMS current could be reduced further if the saturation effect could be removed. Modelling of the magnets suggests that the saturation effects could be reduced if not completely eliminated by changing the current solid coil retaining plates to laminated plates. Further study and measurements would need to be completed to confirm this. The work to complete the change of the plates could be made simultaneously to the magnet shimming.

It is envisaged that the work listed above given adequate resources could be completed during the next two long shutdowns. Most modifications can be made independently without requiring the immediate upgrade of related equipment. For example modifications to the main quadrupole magnet cooling circuit could be made without the upgrade of the cooling station.

Auxiliary ring magnets

Worst case some new magnets would be needed which are relatively low cost items.

Study is still to be completed.

Transfer line magnets

Worst case some new magnets or components will be needed again these are relatively low cost items.

It must be said that several magnets have recently been identified which either need spare units or parts for operation at 1.4 GeV. These projects are now waiting for confirmation of the need to run at 2 GeV operations before decisions for procurement are made. For example the power supply for the BT.BHZ.10 switching magnet has already been identified by TE/EPC as being inadequate for 2 GeV operations. It may be possible with a redesign of the magnet to save the existing power supply (as understood a relatively high cost item) for this a detailed study must be made.

Study is still to be completed.

PS Injection Bumpers, Low Energy Correctors and quadrupoles

Study is still to be completed.

4. MAGNETIC MEASUREMENTS

4.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

- The magnetic instrumentation currently available (i.e. straight flux coils) is suitable for the measurement of integral field and eddy current transients in main dipoles and quadrupoles at various current levels.
- The Holec power supply in 867-RH-29 is able to provide 5515 A @ 30 kA/s, or up to 6000 A at a lower ramp rate to a PSB main dipole (the most demanding case).
- First test results indicate saturation levels up to 6% at 6 kA and small eddy current effects up to 30 kA/s (to be confirmed in Week 19)
- If needed, the measurement of field harmonics will require the development of an ad-hoc multi-coil fluxmeter system (straight or curved).

4.1.1 CRITICAL ISSUES AND PROPOSED CURES

No critical issues identified. Two potential problems that may arise:

- Holec power converter: this is an unique piece at CERN in terms of power and stability, and is apparently very difficult to maintain properly. To guarantee reliability, the possibility of alternative solutions (e.g. refurbishing an old converter used for magnet heating tests in bldg. 150) should be explored.
- PSB B-train system: should eddy current effects have an impact on the new magnet cycles, the possibilities for upgrading the current system could be studied (e.g.: putting on-line the existing NMR probes at high field, etc.)

4.1.2 FURTHER STUDIES NEEDED

- Main dipole: completion of integral eddy current tests in two apertures (one outer and one inner) on one spare unit. Field saturation (and possibly harmonic quality) tests in the final configuration (ramp rate, field level, trim supply current). Should the main coils have to be disassembled and replaced, magnetic side-effects should also be measured.
- Mechanical tests at 2x current levels on a spare dipole in SM18 (see 3.1.2): the integral magnetic field shall be measured during these tests to gain more information on saturation and monitor the response of the magnet.
- Main quadrupole: integral saturation and eddy current tests in two apertures on one spare unit.

4.1.3 INPUT NEEDED FROM OTHER WORK PACKAGES

- Number and type of new or refurbished magnets to be measured.

- Precise definition of powering cycles (magnets have to be tested in the same conditions in which they will be used)
- Field quality tolerances for the beam: BdL/GdL, harmonics, field direction, quadrupole magnetic axis, settling time at the end of ramp-up.

4.2 TECHNICAL DESCRIPTION

Besides the activities described in 4.1.2, the workload of this WP is entirely dependent on the number of magnets that will have to be measured. With the exception of the fluxmeter mentioned at point 4.1, existing instrumentation and infrastructure is adequate for all foreseeable tests (pending conformation of the specifications of new magnets).

As a general rule, the minimum test program for a new or refurbished magnet could include:

- Loadline (magnetization curve): integral BdL/GdL at ~10 current levels
- Eddy current effects: time lag during the ramp-up and overshoot decay time on the flat-top of the main integral field component
- Field quality: integral quadrupole to decapole components at nominal current

However, the details of the program must be specified in accord with magnet group and beam optics for each kind of magnet.

A preliminary breakdown of the possibility activities is as follows:

- Main Dipoles:

Best case scenario: tests on the spare unit demonstrate that the magnetic performance is consistent with calculations and within specs. No further measurements needed.

Worst-case scenario: all units have to be taken out of the ring and modified. Magnetic testing could be envisaged if the position of the main coils is changed significantly.

- Main Quadrupoles: no modifications other than to the cooling circuit are foreseen and no particular need for magnetic measurement is anticipated (to be confirmed by tests on the spare unit)

- Auxiliary ring magnets:

Best-case scenario: nothing to do

Worst-case scenario: if new magnets are made, a small statistical sample of the production may need to be tested. No special problems are foreseen.

- Transfer line magnets:

Best-case scenario: nothing to do

Worst-case scenario: if new magnets are made, a small statistical sample of the production may need to be tested. No special problems are foreseen.

- PS Injection Bumpers, Low Energy Correctors and quadrupoles:

No information available to date

5. RF SYSTEM

5.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

Situation supposing a beam intensity 5E9- 1.65E12 per ring, H=1 or H=2, 8 kV from 160 MeV-2 GeV in a 1.2 s cycle.

- PSB Low Level Beam Control

  If present consolidation program is respected, the required changes can be included for the 2 GeV cycle. Study underway by M.E.Angoletta & A.Blas.

- PSB High Level Cavities and Control

  C02 and C04 RF system:
  Provided the 25 yeas consolidation program is implemented, no problems are expected to cover the new frequency range, digest the additional beam current and supply the increased power.

  C16 RF system:
  The frequency range cannot be extended to 18 MHz (limited to ~ 16 MHz).
  Lowering the blow-up frequency sent to this cavity is the present operational solution, and it will be tested with the new frequency range.
  If higher beam current is required the new scenarios must be defined and studied.

- PSB Transverse Feedback System
  The increase of energy to 2 GeV has only a marginal impact on the specifications (7% more power), so this demand will be included in the study underway by A.Blas to define the system requirements associated with Linac4.

5.1.1 CRITICAL ISSUES AND PROPOSED CURES

This will depend upon the 2 GeV cycle in the PSB.

5.1.2 FURTHER STUDIES NEEDED

For LHC beams and intensities beyond the present LHC nominal intensity, the limitations of the RF systems with a cycle to 2 GeV must be evaluated.

5.1.3 INPUT NEEDED FROM OTHER WORK PACKAGES

• A 2 GeV cycle definition including acceleration duration, Bdot & extraction flat top length.

• We only have one set of hardware, so any changes to the hardware should take into consideration ALL required cycles from the PSB, so the cycles for all beams need to be defined.

5.2 TECHNICAL DESCRIPTION

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6. BEAM INTERCEPTING DEVICES

6.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

The investigation on the existing PSB dump has started. The BTPSTP10 beam stopper also has to be checked for 2 GeV operation. Future objects (H-/H0, Head and tail dump) will take into account the new operational scenario.

6.1.1 CRITICAL ISSUES AND PROPOSED CURES

No showstopper identified.

No spare PSB dump available, new design needed and the production of 2 units has to be launched.

Longer design for the Beam stopper might be necessary. The actual positions would be insufficient to install a larger stopper?

6.1.2 FURTHER STUDIES NEEDED

FLUKA and ANSYS studies. In case of larger dimensions the objects need a new integration study.

6.1.3 INPUT NEEDED FROM OTHER WORK PACKAGES

Parameter table and description of different beams, worst case scenario.

6.2 TECHNICAL DESCRIPTION

Dump:

Option 1: The results confirm the survival of the dump for the upgrade in Intensity and Energy. We built a new spare based on the existing design (with improved cooling)

Option 2: A new design is needed, two new units have to be produced and integration has to be looked at.

Beam stopper:

Option 1: Keep the vacuum tank and modify only the absorber material (unlikely)

Option 2: Adapt a ‘TBSE’ type design. Two units to be produced.

Option 3: A completely new design with the fabrication of two units

For option 2 and 3 the available space will be insufficient. Shifting of the stopper or civil engineering will be needed.

7. POWER CONVERTERS

7.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

Current settings at 2 GeV are assumed to be 1.33 times higher than what is used now at 1.4GeV plus a 10% margin. No changes in optic have been considered. The cycle period is 1.2s.

Booster Injection:

- Booster Injection will be upgraded for Linac 4 connection. No changes needed related the Booster 2GeV upgrade.

Booster Ring:

- The existing supply can not provide the additional RMS current. An increase of peak power, using traditional thyristor technology, would have a significant negative effect on power quality of the Meyrin network 18 kV, which would be inadmissible. The solution will probably be a design similar to the new POPS for the PS, using DC capacitors to store the energy for the pulsating load (civil engineering work required). Inner dipoles and quadrupoles trims will also have to be replaced.
- Dipoles correctors and multipoles converters are mainly used at low energy and have enough margins. They will be consolidated during the shutdown 2011-2012.
- The Qstrips are only used at injection. Any upgrade would be part of the linac 4 project and not of the Booster energy upgrade.
- BDLs are used at ejection but have enough margins.
- The DBS are dedicated to destructive beam measurement and will probably not be used at 2GeV.
- The shavers are only used at injection. Any upgrade would be part of the linac 4 project and not of the Booster energy upgrade.

Booster Ejection:

- BE.SMH 2GeV setting is still within the converter rated current if one considers a 7.5% margin only. The capacitor bank size will have to be adapted to provide the additional energy.
- Even approaching their rated limits, BE DHZ and DVT converters will not need to be upgraded for 2GeV operation.

BT, BTP and BTM transfer:

- BT.SMV20, BT1.SMV10 and BT4.SMV10 settings are still within the converter rated current. The capacitor bank size will have to be adapted to provide the additional energy.
- BT.DVT 30, 40 and 60 will have to be replaced.
- All bendings supplies are already approaching their limits and will have to be replaced for 2GeV operation.
- Quadrupoles supplies on the BT line can handle the additional current at 2GeV, but will have to be replaced in order to allow PPM operation between 1GeV Isolde and 2 GeV PS cycles.

PS Injection and Ring:

- PI.BSM40, PI.BSM42, PI.BSM43 and PI.BSM44 have enough margin to provide the additional current.
- A longer magnet will probably be used for PI.SMH42, keeping the present rating. The capacitor bank size will anyway needed to be adapted to provide the additional energy and a new capacitor charger has to be foreseen.
- PR.DVT, DHZ, QFN, QDN, QSK (150 Power converter in total) will probably have to be upgraded. Today operation of those converters is mainly limited by magnet thermal considerations.

7.1.1 CRITICAL ISSUES AND PROPOSED CURES

Many power converters are not able to deliver the additional current requested for 2GeV operation or not able to guarantee PPM operation between 1GeV Isolde and 2GeV PS. A few converters can be upgraded (capacitor discharge type) but most of the under-rated converters will have to be replaced.

7.1.2 FURTHER STUDIES NEEDED

- Current and voltage ratings exact specification.
- Civil engineering work estimation.

7.1.3 INPUT NEEDED FROM OTHER WORK PACKAGES

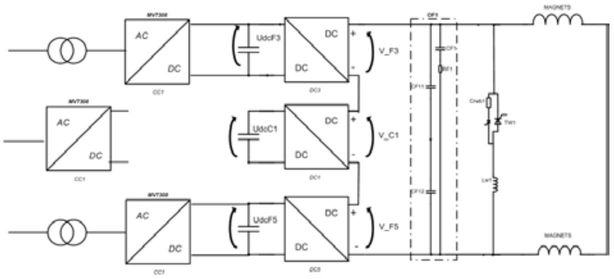
RF and magnets acceleration limitation for the Ring MPS

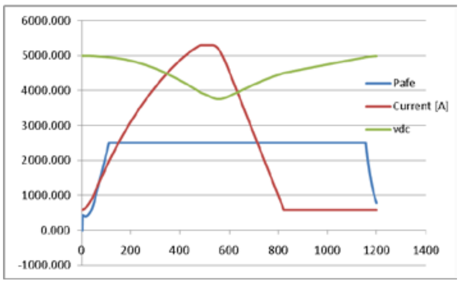
7.2 TECHNICAL DESCRIPTION

Ring MPS:

The basic principle of a POPS-like topology is to manage the energy transfer between the magnets and a huge capacitor bank installed near the power converter. Only the power needed to compensate the losses is driven from the 18kV network, considerably reducing its stress. This would allow more flexibility on the MPS cycle without disturbing other users on the Meyrin site.

- Keeping the existing configuration, the following hardware would be needed:

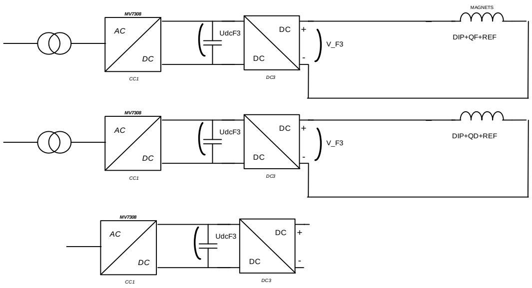


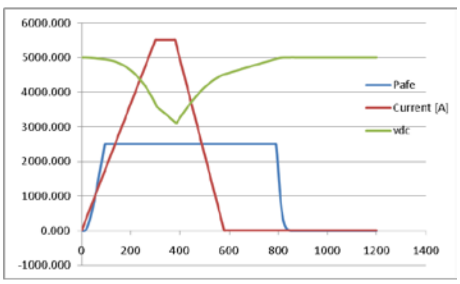


  - 1 new 6000A/4000V main supply
  - 1 (+1spare) new 300A/2000V dipole trim
  - 2 (+1spare) new 400A/700V quadrupoles trims

Limiting factor is the maximum voltage to ground of the magnet (2 kV). For this reason we must apply a maximum of 4 kV to the magnets. What we can do is therefore to realise the cycle proposed above. With the actual PS is not possible because we do not have 4kV on the magnets and the Irms on the transformer is too high. This force us to consider 3200 Arms

- The magnet chain can be divided in two, allowing an increase of the nominal voltage and a faster acceleration. The RMS current could then be reduced to a value close to 1.4 GeV operation. The hardware would then be:





  - 2 new 6000A/3000V main supply
  - 2 (+1spare) new 400A/700V quadrupoles trims

This solution is slightly worst from the minimum voltage point of view. It is possible that the capacitor banks must be slightly increased.

<u>Ring MPS:</u>

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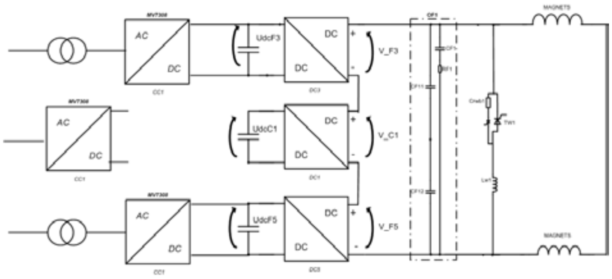
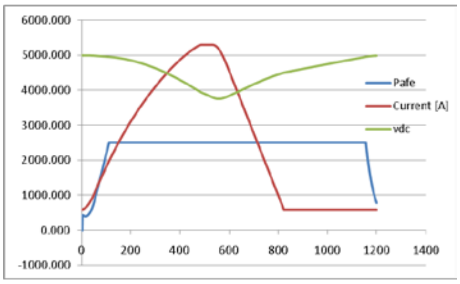
- Keeping the existing configuration, the following hardware would be needed:

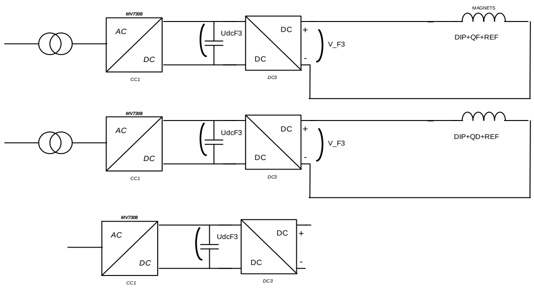


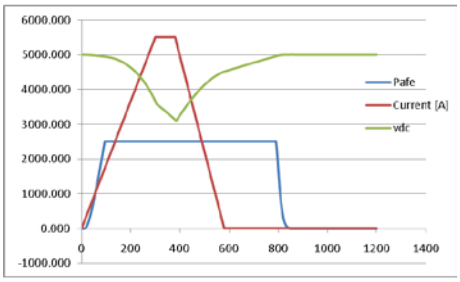


  - 1 new 6000 A/4000 V main supply
  - 1 (+1spare) new 300 A/2000 V dipole trim
  - 2 (+1spare) new 400 A/700 V quadrupoles trims

Limiting factor is the maximum voltage to ground of the magnet (2 kV). For this reason we must apply a maximum of 4 kV to the magnets. What we can do is therefore to realise the cycle proposed above. With the actual PS is not possible because we do not have 4 kV on the magnets and the Irms on the transformer is too high. This force us to consider 3200 Arms

- The magnet chain can be divided in two, allowing an increase of the nominal voltage and a faster acceleration. The RMS current could then be reduced to a value close to 1.4 GeV operation. The hardware would then be:





  - 2 new 6000 A/3000 V main supply
  - 2 (+1spare) new 400 A/700 V quadrupoles trims

This solution is slightly worse from the minimum voltage point of view. It is possible that the capacitor banks must be slightly increased.

8. VACUUM SYSTEM

8.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

The vacuum system of the Booster is divided into three sectors (BR10, BR20, and BR30). Pumping is provided by fixed turbo molecular pumping groups, sputter ion pumps and sublimation pumps which are mounted, together with the Penning/Pirani gauges, on so called manifolds. CERN standard vacuum equipment is used and no special precautions or machine specific spares are needed for 2 GeV operation.

Different beam pipe shapes and vacuum chamber materials were used for the Booster construction: elliptical 0.4 mm thick corrugated chambers (Inconel X750) for the bending magnets, diamond shaped 1.5 mm thick chambers (316LN st.st.) for the quadrupoles, and circular 1.5 mm thick chambers (316LN st.st.) for the long straight sections. The only specific vacuum items used in the Booster are the anodized clamps for the flanges, which are equipped with RF bypasses to minimize the total impedance of the rings.

8.1.1 CRITICAL ISSUES AND PROPOSED CURES

If main machine components, e.g. the magnet system, need to be removed from the Booster ring, a dismantling of the vacuum system would be required. This might lead to surprises and consequences that cannot be judged at the moment. It is therefore recommended to minimize the amount of equipment to be removed from the Booster.

Dynamic vacuum problems are strongly related to beam dynamics issues. Pressure rises, either induced by increased beam loss or electron cloud, are not expected for a 2 GeV Booster operation. On the other hand, electron cloud induced pressure rises might become more significant in the PS.

8.1.2 FURTHER STUDIES NEEDED

No specific study is needed for the Booster vacuum system, but electron cloud studies are needed for the PS. Two dedicated electron cloud experiments are presently installed in straight sections (ss) 98 and 84 of the PS. The vacuum chamber of ss 84 is coated with amorphous carbon and equipped with button-type pickups and a clearing electrode to investigate electron cloud mitigation in the PS, experiments will start in 2010.

8.1.3 INPUT NEEDED FROM OTHER WORK PACKAGES

Input is required from the Beam Dynamics Work Package, especially for the PS.

8.2 TECHNICAL DESCRIPTION

xxx

9. INSTRUMENTATION

9.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

Summary of investigations of present equipment/system with respect to 2 GeV operation

1. Pick-Ups
2. Fast current transformers
3. DC current transformers
4. BBQ tune measurement
5. SEM Grids

6. BLMs
7. FWS

9.2 CRITICAL ISSUES AND PROPOSED CURES

No critical issue has been identified so far.

9.2.1 FURTHER STUDIES NEEDED

Upgrades are needed for the following instruments:

- Pick-Ups: The electronic chain upgrade is included in the consolidation scheme.
- BT.SMV10/20: Depending on the change of septum length, the stack of pick-ups BT. UES10 might have to move.
- DC current transformers:
  - for high ß : Modification of the normaliser modules. Not an issue
  - for high Np : two options
    1. dismount and modify the calibration and feedback windings
    2. new head electronics for increasing the calibration and feedback current.
- BLM: an upgrade is included in the consolidation scheme.
- BT.MTV10i+s, BT.MTV20: three new tanks housing the screens are needed due to the change of length of the vertical septa in the recombination line

9.2.2 INPUT NEEDED FROM OTHER WORK PACKAGES

New length of BT.SMV10 and of BT.SMV20

9.3 TECHNICAL DESCRIPTION

Ring pick-ups:

Replace the Booster orbit measurement system by a trajectory measurement system similar to the one of the PS.

The idea is to have the hardware operational by the time LINAC4 goes on-line.

Ejection pick-ups in the recombination line:

The set of 10 inductive pick-ups, which is to replace the capacitive one, is going to be produced and tested this year. Their integration in the transfer line is also included in the package; BT. UES10 might have to move.

A three-week stop is needed for replacing the present set by the new one: this depends on the next shutdown length (2011 or 2012)

The full upgrade of the electronic chain will be completed in 2012.

The budget is already committed.

DC current transformers:

With operation in the Linac4 era (large number of particles):

The preferred option would be the modification of the head electronics for increasing the calibration and feedback current: 3man.month.

BLMs:

The target is to have at the end of 2012 a basic version of the new system.

Consecutive updates of the firmware during 2013 will bring additional features and better measurements.

MTVs:

Three new vacuum tanks are to be designed and produced for the monitors located downstream the vertical septa in the recombination line.

10. COMMISSIONING AND OPERATION

10.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

There is no specific system assigned to this work package. The work package will be defined by the equipment/system changes of the other work packages.

In the meanwhile, the work package has to provide input for other working groups. For this purpose, an overview of the different beams with their respective beam parameters, as supposed to be provided by the PSB, is given in the appendix, assuming Linac4 injection and 2 GeV extraction energy.

With Linac4 it will be possible to trade off intensity increase (at maximum a factor 2) against transverse emittance decrease. Therefore the values given in the two tables of the appendix are to be understood as a best estimate. In principle, the maximum intensity with Linac4 could be 2.5E13 ppp per ring at the design intensity of the Linac4 source, and new beams or even more challenging beam parameters might be requested by the users at a later stage.

PSB beam parameters with Linac4 intensity and energy of 2 GeV at extraction (an overview of the different beams is given in the appendix).

Injection energy: 160 MeV (revolution frequency ~1 MHz; synchrotron frequency* ~1.68 kHz*)

* at 8 kV, h=1 and 0 synchr. phase; multiply with sqrt(2) for h=2

Extraction energies:

1 or 1.4 GeV (revolution frequency ~1.67 or ~1.75 MHz; synchrotron frequency ~645 or 446 Hz)

2 GeV (revolution frequency ~1.81 MHz; synchrotron frequency ~256 Hz)

Nominal cycling: 1.2 s (0.83 Hz)

10.1.1 CRITICAL ISSUES AND PROPOSED CURES

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10.1.2 FURTHER STUDIES NEEDED

Magnetic cycles should be prepared corresponding to the different commissioning scenarios:

1.) Injection on flat bottom at 160 MeV and slow adiabatic capture (1st commissioning step); start ramp after ~20 ms

2.) Injection on a ramp (dB/dt of ~1.21 T/s currently assumed) to minimize space charge effects (2nd commissioning step with Linac4)

The average dB/dt with the current MPS is ~2.65 T/s, varying significantly over the range of MPS current (decreasing with increasing current). For synchronization, a minimum duration of the flat top of 25 ms has to be reserved.

10.1.3 INPUT NEEDED FROM OTHER WORK PACKAGES

Operational limitations of a potential new MPS and RF system have to be taken into account. The commissioning steps and time lines for the PSB 2 GeV upgrade can only be defined after input from each single work package.

10.2 TECHNICAL DESCRIPTION

A list of beams including projected beam parameters with Linac4 as PSB injector has been compiled (see appendix). A magnetic cycle from 50 MeV to 2 GeV (1.2 s) with injection on a ramp, respecting the limitations of the currently installed MPS (except for the required current), has been proposed and is available in a separate file. A plot of the proposed B-field and revolution frequency for this cycle is shown in the appendix.

The upgrade proposals of the other work packages have to be included in the commissioning planning.

11. EXTRACTION, TRANSFER, PS INJECTION

11.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

BE.BSW: magnets and generators OK up 2.2 GeV;

BE.KFA14L1: not enough margin on magnets (OK up to 1.7 GeV, ferrite saturation above); design new magnets and vacuum vessel. Generators OK up to 2 GeV;

BE.SMH: magnet succesfully tested at current equivalent to 2 GeVoperation; cooling and interconnects to be reinforced;

BT.SMV10: not enough margin on magnet (OK up to 1.75 GeV); longer magnet to be designed;

BT.KFA10: magnets and generators OK up to 2 GeV; it is advisable to replace the ferrites by more performant ones to run at 2 GeV or higher;

BT.SMV20: not enough margin on magnet (but OK up to 1.9 GeV); longer magnet to be designed;

BT.KFA20: magnets and generator OK up to 2 GeV;

PI.SMH42: not enough margin on magnet (1.4 GeV max.). Needs new PS injection scheme to accomodate the additionally required length for the septum magnet;

PI.KFA45: magnets OK but no margin on generator (1.4 GeV is the limit if magnets are terminated)If magnets are used in short-circuit mode, 2 GeV is attainable, but with increased rise and fall times as well as increased ripple on the flattop.

11.1.1 CRITITAL ISSUES AND PROPOSED CURES

Up to 1.7 GeV all PSB septa and kickers are OK. For 2 GeV operation the PSB extraction kicker and recombination septa need a full redesign and new construction. To provide space for the longer Beam Transfer septa (while retaining the complex vacuum vessels) it is proposed to move the beam screens to the adjacent vacuum chambers.

For PS injection no margin exists on the present either on the septum or on the present kicker system. A new injection scheme is needed to provide the additional space for a longer septum, as well as allow the use of the injection kicker in short circuit mode with the associated degradation of rise, fall time and ripple at the flattop.

Two options are being explored: injection in PS straight section 42 (present PS injection location, standard PS short straight section), or displace the injection region to straight section 41 (PS standard long straight section, in which little equipment is installed at present).

11.1.1.1 OPTION 1: INJECTION IN SD42

The simplest solution is to inject into SD42 as at present, which requires a longer injection septum, and a ~14 mrad bumper integrated into the septum tank. The KFA45 kicker can be operated in short-circuit mode for LHC beam if the blow-up due to the increased ripple is acceptable – if not, a new supplementary kicker can be built in SD53, with about -1 mrad. The details of the aperture limits for the circulating and injected beam still have to be checked for the solution with a supplementary kicker in SD53.

If the integration of the bumper and septum in SD42 is not possible, the next best solution looks like building a shorter under vacuum bumper septum in 42, and then adding a bumper in SD41, to approach the present injected angle. The bumper in SD42 would need to provide about 7 mrad, and the details of the aperture limits for the circulating and injected beam have to be checked (the orbit increases by about 10 mm in main magnet 41, and the trajectory of the injected beam is about 3 mm further out, in main magnet 42).

11.1.1.2 OPTION 2: INJECTION IN SD41

If injection in SD42 is not found to be technically possible, then injecting into SD41 has been looked at. There is plenty of space for the septum and an adjacent bumper, and the kicker strength required is lower, as the phase advance and beta are favourable. However, the beta functions are large at the septum location and the consequent larger beam size will not fit easily into the aperture. Possibly a temporary perturbation of the injection optics would allow the beam sizes to be reduced enough to make such a scheme possible, or replacement of existing chambers with enlarged ones. The present KFA45 could stay where it is, but a total of 5 bumpers would be needed, together with a longer septum.

11.1.2 FURTHER STUDIES NEEDED

To provide space for the longer beam transfer septa, it is envisaged to displace the beam observation equipment downstream. For the MTV screens in the BT.SMV10 and BT.SMV20 vacuum vessels, a short integration study should be able to point out the most economical approach to re-install the existing screens. At first sight, a redesign and new construction of the vacuum chambers immediately downstream of BT.SMV10 could possibly provide the required flanges for the mechanisms and viewport necessary, within any further impact on the septa vacuum vessels. Alternatively, the vacuum vessels (covers) could be stretched, which in case of BT1.SMV10, will lead to necessary modifications of the support structure of the septa. To relocate the screen of the BT.SMV20 the vacuum vessel cover could be stretched and the adjacent vacuum chamber downstream of the septum would have to be adapted.

A new PS injection scheme needs to be developed, to provide space for a longer septum magnet as well as to cope injection kicker system parameters with the kicker in short-circuit mode.

The limitations and performance of a bumper in the same straight section as the injection septum in SD42 are still to be finalized. This should determine if the injection region should be moved.

The impact of the flattop ripple on the LHC beam emittance, due to running the injection kicker in short-circuit mode is to be verified. This should be subject of a future MD, and could determine the need for supplementary kicker (in SD53?).

11.1.3 INPUT NEEDED FROM AND PROVIDED TO OTHER WORK PACKAGES

Extracted beam parameters for all users.

The beam observation screens on the vacuum vessels for the Booster transfer line septa need to be moved to the adjacent vacuum chambers to provide space for the new septa magnets.

The impact on the conventional magnets in the BT and BTP line and PS depends strongly on the injection scheme which will be implemented and still needs to be determined.

To obtain the required increased magnetic strength of the PSB extraction septa, the current of the septa will have to be increased (power supply under the responsibility of EPC). The magnets are not expected to saturate and no electric parameter changes are expected from the required mechanical reinforcement that will be implemented.

To obtain the increased magnetic strength for the BT septa, the magnets will be stretched by approximately 24% (with the associated increased in inductance and resistance of these) and the remaining 6% will have to be obtained by increasing the current of the devices. The power supplies of these septa will have to be upgraded accordingly (under responsibility of EPC).

11.2 TECHNICAL DESCRIPTION

11.2.1 BOOSTER EXTRACTION BUMPERS BE.BSW14L4, 15L1, 15L4.

The magnet current at 1.4 GeV is 525 A (data from 2009 run). At 2.17 GeV, 724 A would be required. The magnets are of booster type 5 (Imax = 765 A) and type 6 (Imax = 845 A) and can be used. The generator voltage will be ~ 460 V which is achievable. Conclusion: no problem with the present system.

11.2.2 BOOSTER EXTRACTION KICKER BE.KFA14L1

The kicker consists of 4 delay line magnets (= 25 Ω) pulsed in parallel for each booster ring. Their generator consists of a gas filled Pulse Forming Line (rated 60 kV) discharged by a 60 kV thyratron.

The maximum PFL voltage required at 1.4 GeV is 42.5 kV (data from 2009 run for ring 2).

The thyratron life time which is more than ten years in the present working conditions is expected to decrease with the new ones. In order to keep 10 % margin, the PFN voltage should be kept below 55 kV. The corresponding beam energy is close to 2 GeV. A few nanoseconds (~1 to 5) rise time are expected to be lost as a consequence of the voltage increase.

Induction in the air gap: $B_{air} = \mu_0 \times I / h$ where I is the magnet current and h the gap height.

$$B_{air} = 4 \times \pi \times 10^{-7} \times 2351 / 0.07 = 0.0422 \text{ T}$$

Induction in the ferrite: $B_f = B_{air} \times S_{air}/S_f$ where S is the cross sectional area.

For the air gap, we have $S_{air} = w_{air} \times lcell$ where wair is the gap width and lcell the magnet cell length.

For the ferrite, we have $S_f = w_f \times l_f$.

This gives: $B_f = 0.0422 \times 0.1175 \times 0.032 / 0.026 \times 0.026 = 0.2347$ T.

In the end cells, the induction in the ferrite is 50 % higher (0.3520 T) and is 17.3 % above the maximum acceptable figure of 0.3 T corresponding to the start of saturation (for 8C11 and CMD5005 grades). The maximum magnet current corresponding to 0.3 T is 2000 A (VPFL = 50 kV), which corresponds to a beam energy of only 1.75 GeV.

Conclusion: Operation at 2 GeV requires a new ejection kicker tank. The actual tank should also be upgraded to serve as a spare which does not exist for the moment. There won't be any margin.

11.2.3 BOOSTER EXTRACTION SEPTUM BESMH

The present extraction septa use laminated steel magnet cores. The present magnetic field is around 0.35 T at the peak current 7.2 kA. This design provides sufficient margin to increase the current to obtain the required field for operation with 2 GeV beams. A magnet block was successfully tested up to 11 kA, and the magnet behaviour was still relatively linear. However, the magnets for ring 1 and 2, as well as for 3 and 4 are put electrically and hydraulically in series und? with connections inside the vacuum vessel. The hydraulic circuit will have to be modified so that the magnets can be cooled in parallel to cope with the additional heat dissipation due to the higher currents. The electrical series connections will need to be reinforced to withstand the higher mechanical loads. These are considered minor modifications and could be carried out on the operational spare magnet and after this one has been installed, the magnet removed from the ring could be modified. The exchange of the BESMH for its upgraded version can be planned in any shutdown which allows 4 weeks of access to the Booster extraction area.

11.2.4 BOOSTER TRANSFER SEPTA BT1SMV10, BT4.SMV10

Each of these septa are used (2010) at slightly below their design current of 27.3 kA. To maintain their estimated lifetime at present values, taking into account the high number of pulses annually, it is necessary to lengthen the magnets. The present vacuum vessels could provide space for a 1300 mm magnet (presently 1060 mm) if the installed beam observation screen would be moved to the adjacent vacuum chamber. This would yield a magnet with a magnetic length of approx. 1236 mm, which would need 28.6 kA. It is expected that the life time of these magnets (presently around 5 years) would only be slightly reduced. A new adjacent vacuum chamber would have to be designed and manufactured, to allow the installation of the present beam screens as well as the pumping group already installed in that area. Due to the increase yoke length, the vacuum would degrade up to 25% if the pumping speed would be kept constant.

11.2.5 BOOSTER TRANSFER KICKERS BT1.KFA10, BT4.KFA10.

Each kicker consists of 2 delay line magnets (Z_0 = 12.5 Ω) pulsed in parallel. Each generator consists of a gas filled Pulse Forming Line discharged by a 60 kV thyratron. The pulse generators have the same limitations as the BE.KFA ones. In order to keep 10 % margin, the PFN voltage should be kept below 55 kV. The corresponding beam energy is close to 2 GeV. A few nanoseconds (say 1 to 5) rise time are expected to be lost as a consequence of the voltage increase.

The maximum PFL voltage required at 1.4 GeV is 42.5 kV (data from 2009 run).

At 2.17 GeV, the voltage required will be 59 kV corresponding to a current of 4702 A in each magnet. The thyratron life time which is more than ten years in the present working conditions is expected to decrease with the new ones.

Induction in the air gap: $B_{air} = 4 \times \pi \times 10^{-7} \times 4702 / 0.11 = 0.0537$ T.

Induction in the ferrite: $B^{f} = 0.0537 \times 0.053 \times 0.032 / 0.026 \times 0.026 = 0.135$ T.

In the end cells, we have 0.2020 T which is on the limit for the present 4L1 ferrite grade.

Therefore, it is recommended to replace the present 4L1 ferrite by 8C11 or CMD5005 to guarantee the kick maximum value because the µ of 4L1 is about half of 8C11.

This move would also improve vacuum performances because present ferrite cores are glued with epoxy resin. The construction of a spare tank may also be envisaged.

Conclusion: Operation at 2 GeV is possible but a change of ferrite grade is recommended. The construction of a spare tank could also be foreseen. There won't be any margin.

11.2.6 BOOSTER TRANSFER SEPTUM BT. SMV20

This septum is used at slightly above its design current of 27.2 kA (2010 25.5 kA). To maintain their estimated lifetime at present values, taking into account the high number of pulses annually, it is necessary to lengthen the magnet as well. The present vacuum vessel could provide space for a 1300 mm magnet (presently 1060 mm) if the installed beam observation screen would be moved to the adjacent vacuum chamber. This would yield a magnet with a magnetic length of approx. 1236 mm, which would need 26.4 kA. It is expected that the life time of these magnets (presently around 10 years) would only be slightly reduced. A new adjacent vacuum chamber could be designed and manufactured, to allow the installation of the present beam screens or an extended septum vacuum vessel cover which would provide a flange for the beam observation system in a similar way as in the present system. Due to the increase yoke length, the vacuum would degrade up to 25% if the pumping speed would be kept constant.

11.2.7 BOOSTER TRANSFER KICKERS BT.KFA20.

The kicker consists of 2 delay line magnets (Z_0 = 12.5 Ω) pulsed in parallel. The magnets are identical to the BTi.KFA10 ones but the pulse generator configuration is not. In order to gain a few nanosecond rise time, the magnets are part of the PFL and are then charged to the full PFL voltage. The actual thyratron is rated 40 kV but can be replaced by a 60 kV one. A few nanoseconds (say 1 to 5) rise time are expected to be lost as a consequence of the voltage increase. The maximum PFL voltage required at 1.4 GeV is 28 kV (data from 2009 run). The magnet voltage hold-off is limited to 37 kV. This corresponds to a beam energy of 2.04 GeV.

The possibility of modifying the pulse generator to work in the same conditions as the BT.KFA10 ones exists. The kick rise time (2-98) % will then increase from 87 ns to 100 ns. It will be the same as the BTi.KFA10 rise time. The ferrite grade is 8C11 or CMD5005 and a spare tank exists.

Conclusion: the BT.KFA20 can be used without modifications up to 2 GeV. There won't be any margin.

11.2.8 PS INJECTION SEPTUM PI.SMH42

Still under study.

11.2.9 PS INJECTION KICKER PI.KFA45

Each of the four KFA45 magnet modules can be used in terminated or short-circuit mode.

The generators consist of a gas filled Pulse Forming Line discharged by a 100 kV thyratron. Another thyratron is used to short-circuit the magnet terminator when the short-circuit mode is requested. When used is short-circuit mode, the kick is increased by 82 % at full PFL voltage (80 kV). The drawbacks are:

-increase of flattop ripple from ± 2 % to ± 3 %

-increase of post pulse ripple from ± 1.25 % to ± 1.5 %

-increase of rise time (2-98)% from 42 to 68 ns

-increase of fall time (98-2)% from 68 to 87 ns

If the short-circuit mode is not suitable, an additional kicker is required.

The main concerns are:

-unavailability of high voltage gas filled cables used for the PFL and transmission. At present, no potential manufacturer has been identified and it is unlikely we find one.

-no space available in the present 365 building

So, an additional kicker should have a rather small deflection angle to permit the use of standard available cables.Conclusion: if the system can't be used in short-circuit mode, development of new generators with PFL or Pulse Forming Network is required. The solution with PFL is highly desirable for complexity reduction and optimized performance but it depends on the availability of critical components in industry.

11.2.10 ADDITIONAL PS INJECTION KICKER (KFA 53?)

Still under study.

12. CONTROLS

12.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

Due to the increase of energy up to 2GeV some of the Controls systems have been checked in order to guarantee that Controls is able to provide an adequate response. Only two components were identified as a possible showstoppers: Function generators (GFAS) and Synthetic B-Train.

- GFAS: When defining a magnetic cycle, a function generator (module GFAS) is used in order to provide the function reference for the main power supply. This module GFAS in able to provide a transition from 0 to the maximum value in 35ms with a frequency of sampling of 200KHz.

- Synthetic B-Train: Precise information in real time of the magnetic field, as a function of time, is important for beam control as well as for many measurement applications. For the time being the most severe demand in PSB is 0.3 Gauss precision and 0.1 Gauss resolution. The information about the magnetic field is synthetically generated (Synthetic B-Train) following a magnet model with some feedback from real acquisition of the magnetic field. This Synthetic B-Train has a resolution of 0.1 Gauss with a frequency of 400Khz.

12.1.1 CRITICAL ISSUES AND PROPOSED CURES

Feedback from equipment groups are required in order to know if the current design of the Synthetic B-Train is still valid. Regarding the module GFAS no problems are expected as the response of that module is quite fast, although some checking will be done as soon as the information of the 2GeV cycle is received.

12.1.2 FURTHER STUDIES NEEDED

Depending on the request of the equipment groups (new installations, modification of existing installation, hardware or software) further studies should take place.

12.1.3 INPUT NEEDED FROM OTHER WORK PACKAGES

Some information is required in order to validate the Controls systems:

- It is still valid a resolution of 0.1 Gauss? What is the precision required?
- Could the new magnetic field be generated with the current configuration of the Synthetic B-Train: frequency of 400KHz with a resolution of 0.1 Gauss?

Requirements in terms of new hardware and software installation, as well as modification of the current systems.

12.2 TECHNICAL DESCRIPTION

Waiting for feedback from equipment groups to fill this point.

13. ELECTRICAL SYSTEMS

13.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

The booster network is fed from ME*9 substation, in an antenna configuration.

Attention has to be drawn on all the ongoing projects on the Meyrin site (Linac4 , 513, POPS), affecting the total consumption on EHT102/1E and MP5.

The future electrical distribution (LV&HV) of the Booster complex will very much depend on the future power request of Booster end users (mainly TE and EN/CV).

The actual power consumption is fluctuating around 10 MVA.

A 25% increase of the power is conceivable.

Before going any further with the detailed studies, EN/EL need a proper estimation of the power needed, including all Booster end users.

13.1.1 CRITICAL ISSUES AND PROPOSED CURES

No more power is available on the transformer dedicated to the general services.

Since the 18 kV cubicles are of an old type, any extension of the existing HV switchboard is not possible with the existing cubicle type. EN/EL will have to replace all the cubicles of this ME*25 substation, in case of a need for new HV feeders.

The 18 kV power cables feeding the booster are 40 years old. The status of these cables shall be verified and might require some consolidation/exchange.

13.1.2 FURTHER STUDIES NEEDED

Studies concerning the future distribution network are mandatory. This study will be done for the booster (HV&LV) distribution and its integration in the current Meyrin electrical distribution.

13.1.3 INPUT NEEDED FROM OTHER WORK PACKAGES

In order to start these studies, a balance sheet concerning the needed power is necessary, including all users of the Booster.

13.2 TECHNICAL DESCRIPTION

xxx

14. COOLING AND VENTILATION

14.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

This is ongoing; before any answer we need a confirmation on requests (cooling powers, flow rates, pressures etc.) both for water cooling and for air conditioning.

14.1.1 CRITICAL ISSUES AND PROPOSED CURES

For the time being the most critical issue will be the length of shutdown to comply with the work to be performed. This includes commissioning time for CV installations and all tests on users' equipment can be done only after the completion of our intervention.

Basic assumption is that the necessary resources (material and manpower) shall be provided according to the planning requests.

14.1.2 FURTHER STUDIES NEEDED

Full definition of new cooling and ventilation installations.

14.1.3 INPUT NEEDED FROM OTHER WORK PACKAGES

Cooling powers, flowrates, max pressure, acceptable pressure drops and temperature range for water cooled systems (chilled water, raw water, demineralised water).

Same for compressed air needs.

Safety file, RP constraints, heat dissipations in air etc. for HVAC systems and fire extinction needs.

14.2 TECHNICAL DESCRIPTION

According to first input received, the increase of working pressure and of cooling power will require the complete replacement of the cooling station and of distribution piping that is not sized for an increase of flow rate nor of pressure. Once more detailed will be provided, a decision on whether the same number of circuits will be kept or additional circuits (at different working conditions) and consequent space shall be needed.

15. RP AND SAFETY

15.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

Prompt radiation levels and activation of accelerator components related to injection into the PSB are expected to rise by a factor of 2 because of the proton beam intensity increase enabled by Linac 4.

Furthermore, radiation levels and activation at terminal energy of 2 GeV in the PSB and in the PS injection will rise by a factor of 1.3 with respect to 1.4 GeV .

These two effects combined, plus an allowance for non-linear effects which scale more than proportional to beam intensity may lead to radiation level increases by a factor between 2.5 and 3

15.1.1 CRITICAL ISSUES AND PROPOSED CURES

The increased radiation levels coming with the energy- and intensity upgrade are a concern for beam insertions and aperture limitations which are active at terminal energy – foremost the extraction kicker or septa, the transfer line, and the injection septum into the PS.

Radiation levels on the crossing point of Route Goward are already exceeding the limits for areas accessible to public, this situation may become aggravated. Shielding of the road passage will become mandatory.

In the RAMSES 2 light project, a radioactive release monitor will be fitted to the PSB ventilation extraction for the first time. Releases rise proportionally to other radiation effects with intensity- and energy increases. The impact on the total release figure of the Meyrin site, including ISOLDE, n-TOF, TT10 is as yet unknown. If action levels/ optimisation thresholds could be regularly exceeded, modifications to the ventilation system will become necessary.

Independent of the energy rise, radiation effects related to the injection into PSB from Linac4 must be studied. In particular, the injection dumps must be designed such that residual radiation can be shielded during shutdowns.

15.1.2 FURTHER STUDIES NEEDED

Relation of measured or estimated beam loss (BE/ABP, BE/OP) to activation levels (DGS-RP).

Assessment of estimated and measured radioactive releases with the environmental impact model.

15.1.3 INPUT NEEDED FROM OTHER WORK PACKAGES

From BE/ABP: best estimates of beam loss figures for more intense, more energetic beams in PSB, incorporating non-linear effects.

From EN/CV: ventilation flows required to remove extra heat from energy increase, planned lay-out of future ventilation system.

15.2 TECHNICAL DESCRIPTION

xxx

16. TRANSPORT AND HANDLING

16.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

The major transport and handling equipment listed below is despite its age in reasonable condition for the present intervention scenarios.

- CH-066/067 SMISO 10t trailers; 1970; bldg.361
- PR-0138 MUNCK 20t crane; 1970; bldg 361
- AS-045 GEBAUER 2t lift;1970, bldg 361
- PR-134/135/136/137 MUNCK 10t cranes;1970; bldg.360

The consolidation (replacement) of the lift is the most urgent and will take about six weeks and could be done at the next long shutdown. It may be required that the new lift will be ‘interlocked’ to avoid the use during machine operation.

There will be most likely a need for new auxiliary handling equipment such as hoists, slings, spreader beams etc.

16.1.1 CRITICAL ISSUES AND PROPOSED CURES

There are no critical issues identified from our part so far as long as the Booster machine components keep their present characteristics in terms of dimensions, weight, lifting points, sensitivity regarding vibrations, shocks etc.

If higher capacity handling equipment is required then it must be checked for example if the building 360 structure will allow the installation of cranes with capacities higher than 10t.

16.1.2 FURTHER STUDIES NEEDED

Feedback from the equipment responsibles.

16.1.3 INPUT NEEDED FROM OTHER WORK PACKAGES

Integration: All modifications must be cross-checked with required transport zones

Radiation: Increased radiation values may require optimized (i.e. remote controlled) transport and handling equipment and/or additional shielding (which then becomes again an integration problem).

16.2 TECHNICAL DESCRIPTION

xxx

17. SURVEY

17.1 SURVEY OF EQUIPMENT/SYSTEM WITH RESPECT TO 2 GEV OPERATION

All equipment and methods needed for the existing magnet of PSB and Transfer Lines are ready and no changes needed for 2 GeV operation.

Consolidation for the existing lines is programmed for the next shut-downs and was scheduled with the machine responsible.

17.1.1 CRITICAL ISSUES AND PROPOSED CURES

If the main dipoles have to be taken out: risk to lose the stability of the geometry; we need to take out all 1st magnets, realign them, and in a second step take out the other 16 (2nd magnets of a sector).

17.1.2 FURTHER STUDIES NEEDED

Investigate about the geometry transfer between the PS Hall and the PSB to smooth the BI line.

In the case that the main dipoles have to be taken out: careful studies of impact on the overall geometry of the Booster Ring needed.

17.1.3 INPUT NEEDED FROM OTHER WORK PACKAGES

As soon as the design study starts for any new element to be aligned, we would like to be involved for alignment target and support design.

This information should come from WP 2, 4, 7, and 9.

17.2 TECHNICAL DESCRIPTION

xxx

18. SUMMARY AND RECOMMENDATIONS

19. REFERENCES

[1] LHC Performance Workshop Chamonix 2010, http://indico.cern.ch/conferenceOtherViews.py?view=standard&confId=67839

[2] S.Aumon, PhD thesis, in preparation.

[3] xx

[4] xx

20. APPENDIX

20.1 MD PROPOSALS

Proposed MD for the study of the transverse instability at flat top in the PS

The idea is to reproduce the transverse instability observed in the PS in 2001, 2004 and 2006 at 26 GeV/c, and study in detail its dependence on bunch intensity and length. The goal is to determine the source and the behaviour of this instability and extrapolate from all the observations and studies whether it can act as a serious bottleneck to get the LHC25 beam through the injector chain, once its intensity is potentially doubled.

We need to use an LHC25 beam (with intensity up to the highest that can be produced in the PSB) with bunches which we adiabatically shorten at flat top to values around 10ns, till the beam becomes unstable (with corrected chromaticities). We could try to determine the threshold bunch length (i.e. the one below which the beam is unstable) as a function of the injected intensity. Is the instability only horizontal or does it appear also in the vertical plane? Measurements (in both planes) with the wall current monitor WCM00 used by Sandra for the study of the TMCI at transition crossing could be useful to see the intra-bunch motion while the instability grows.

If possible, the measurements should be done both with the LHC25 user (multi-bunch, by eventually varying the number of bunches up to 72) and with the LHCINDIV (single bunch), in order to pin down whether this is a multi-bunch or single bunch effect (including in the “multi-bunch” also a possible single bunch electron cloud instability).

Parallel electron cloud measurements can be taken with Edgar’s set up in order to find out whether there is a direct correlation between the appearance of the electron cloud, which is known to be present in the PS when the bunches of the LHC25 become short enough, and the observed instability.

The transverse pick-up signals and the screen in TT2 could be used to cross check the electron cloud build up and beam quality also in the transverse line.

20.2 BEAMS TO BE DELIVERED BY THE PSB (AFTER UPGRADE)

Table 1: Overview of LHC-type beams to be delivered by the PSB with Linac4 and after energy upgrade.

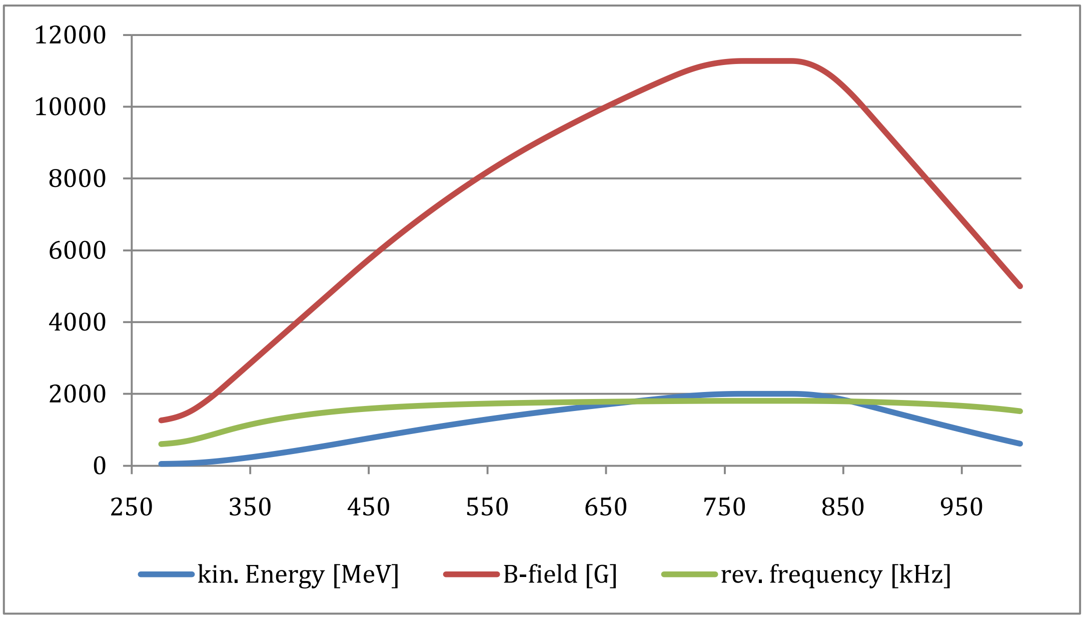
user	harm. at extr.	PSB rings used	intensity per ring	rms emittance at extr. [mm mrad]	bunch length at extr. [ns]	extr. energy [GeV]
LHC25A/B	1	1-4 and 3+4 (2 extractions)	2.43E12 (ultimate) and smaller	hor.: ≤2.5 vert.: ≤2.5	180	2
LHC25	2+1	2-4	3.25E12 (nominal) and smaller by factor 20	hor.: ≤2.5 vert.: ≤2.5	140	2
LHC50	2+1	2-4	for ultimate expect also 2.43E12 (2 bunches/ring)	hor.: ≤2.5 vert.: ≤2.5	140	2
LHC75	2+1	2-4	variable, but smaller than 25 and 50 ns	hor.: ≤2.5 vert.: ≤2.5	140	2
LHCPILOT	1	3	0.005E12	hor.: 2.5 vert.: 2.5	85	2
LHCPROBE	1	3	0.005-0.023E12	hor.: ≤2.5 vert.: ≤2.5	70	2
LHCINDIV	1	1-4	0.023-0.135E12	hor.: ≤2.5 vert.: ≤2.5	80-85	2

Table 2: Overview of fixed-target physics beams to be delivered by the PSB with Linac4 and after energy upgrade.

user	harm. at extr.	PSB rings used	intensity per ring	rms emittance at extr. [mm mrad]	bunch length at extr. [ns]	extr. energy [GeV]
CNGS	2	1-4	0.6-8E12 + ~45% increase to reach target limit	hor.: ~10 vert.: ~8 ~12/7 with MTE	180	2
SFTPRO	2	1-4	<6E12 – would an increase be desirable?	hor.: ~6-8 vert.: ~5-6 ~12/7 with MTE	180	2
AD	1	1-4	4E12 (currently)	hor.: ~8 vert.: ~6	190	2
TOF	1	1-4	<9E12 (currently)	hor.: ~10 vert.: ~10	230	2
EASTA/B/C	1	3 (+2)	~0.1-0.45E12	hor.: ~3 vert.: ~1	150	2
NORMGPS NORMHRS	1	1-4	up to 10E12 (currently – increase with HIE-ISOLDE?)	hor.: ≤15 vert.: ≤9	250	1 or 1.4
STAGISO	1	2-4	<3.5E12	hor.: <8 vert.: <4	230	1 or 1.4

20.3 PROPOSED MAGNETIC CYCLE FROM 50 MEV TO 2 GEV

The data are available at [ref]



20.4 COST AND MANPOWER ESTIMATE

In the following sections, the cost estimate is summarised for every single work unit as well as in a summary table. The cost for manpower is included in the cost estimate wherever additional manpower (fellows, associates) is requested. Existing CERN staff is not accounted for in terms of cost, but the required FTE are given.

20.5 TIME LINES

In the following sections, the time lines are given for each particular work unit as well as in a summary graph.