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LHC Injectors Upgrade

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Feasibility and Impact of 900 ms Operation of the PSB

ABSTRACT:

In the frame of the LIU-PSB upgrade project keeping the present length of a basic period of 1.2 s is the baseline scenario. However, it is also judicious to design all new equipment such that it is compatible with 900ms operation if ever this operation mode should be envisaged in the future.

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1. INTRODUCTION

In the frame of the LIU-PSB upgrade project keeping the present length of a basic period of 1.2 s is the baseline scenario. However, it is also judicious to design all new equipment such that it is compatible with 900ms operation if ever this operation mode should be envisaged in the future. This document shall answer, equipment by equipment, the following questions:

- Which equipment is limiting the cycling rate to 1.2s (old or new equipment)?
- What is the additional cost if new equipment would have to be compatible with 900 ms instead of 1.2 s?
- How much would remain to be invested for upgrading old equipment for 900 ms cycling?
- Are we only considering 900 ms cycling for all users, or is there a possibility to cycle at 900 ms for LHC only? Is there a significant different in cost?

1.1 [LEVEL 2 TITLE]

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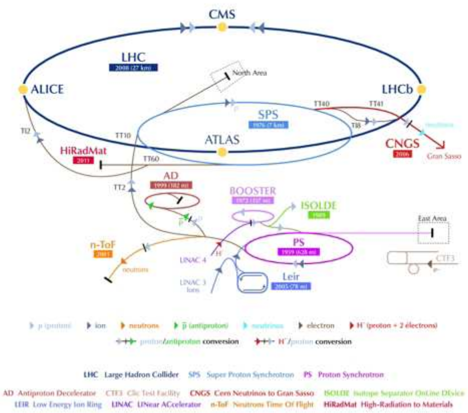

Figure 1 — [Caption of the figure]

[1] [Foot note]

Table 1 — [Caption of the table]

2. Magnets [Newborough]

2.1 Equipment limiting the cycling rate (old and new)

xxx

2.2 Modifications needed to make existing equipment compatible with 900 ms operation and associated additional cost

xxx

2.3 Modifications needed to make new equipment compatible with 900 ms operation and associated additional cost

xxx

2.4 900 ms for all cycles vs. 900 ms for LHC cycles only: difference in workload and cost

xxx

2.4.1 [LEVEL 3 TITLE]

2.4.1.1 [LEVEL 4 TITLE]

3. RF System [Findlay, Paoluzzi, et al]

3.1 Equipment limiting the cycling rate (old and new)

xxx

3.2 Modifications needed to make existing equipment compatible with 900 ms operation and associated additional cost

xxx

3.3 Modifications needed to make new equipment compatible with 900 ms operation and associated additional cost

xxx

3.4 900 ms for all cycles vs. 900 ms for LHC cycles only: difference in workload and cost

xxx

3.4.1 [LEVEL 3 TITLE]

3.4.1.1 [LEVEL 4 TITLE]

4. Power converters (Linac4 injection) [Nisbet]

4.1 Equipment limiting the cycling rate (old and new)

xxx

4.2 Modifications needed to make existing equipment compatible with 900 ms operation and associated additional cost

xxx

4.3 Modifications needed to make new equipment compatible with 900 ms operation and associated additional cost

xxx

4.4 900 ms for all cycles vs. 900 ms for LHC cycles only: difference in workload and cost

xxx

4.4.1 [LEVEL 3 TITLE]

4.4.1.1 [LEVEL 4 TITLE]

5. Power Converters (2GeV upgrade) [Pittet]

5.1 Equipment limiting the cycling rate (old and new)

Ring Corrector magnets have enough margins to run with 900ms cycles.

The present Booster MPS baseline does not allow for 900ms operation.

Most of the power converters in the PSB-PS transfer line will have to be replaced or upgraded for 2GeV operation. 900ms cycles is not covered by the present baseline.

5.2 Modifications needed to make equipment compatible with 900 ms operation and associated additional cost

A 30% increase on the rated voltage and/or on cooling capability must be foreseen for most of the power converters. A corresponding 30% increase on the 2GeV upgrade converter cost is expected.

5.3 900 ms for all cycles vs. 900 ms for LHC cycles only: difference in workload and cost

5.3.1 Booster MPS

According to the study presented by A.Blas, 900ms cycles for LHC can be achieved with the present Booster MPS baseline (https://indico.cern.ch/conferenceDisplay.py?confId=184980). This leads to a significant cost reduction compared to the option with 900ms for all users, considering the weight of the MPS in the project.

Current and voltage waveforms

Semiconductors temperature

5.3.2 PSB-PS transfer line

There is not much difference on the PSB-PS transfer line converters to have all cycles or LHC cycles only at 900ms. The cooling capability only would not have to be significantly increased. A 25% increase on the converters cost is still expected.

6. Beam Instrumentation [Tan]

There may be no impact, in this case skip this section

6.1 Equipment limiting the cycling rate (old and new)

xxx

6.2 Modifications needed to make existing equipment compatible with 900 ms operation and associated additional cost

xxx

6.3 Modifications needed to make new equipment compatible with 900 ms operation and associated additional cost

xxx

6.4 900 ms for all cycles vs. 900 ms for LHC cycles only: difference in workload and cost

Xxx

7. Beam Intercepting Devices [C. Maglioni]

Beam intercepting devices in the PS Booster region are:

- the **PSB dump** : the main dump located at the booster extraction at the end of the BTM line. The present device has to be dismantled and replaced with a new one, currently under design.
- the **BTP.STP-10** stopper, located at the booster extraction on the BTP line to the PS: this stopper has been revised recently. Due to its nature, a stopper is not affected by a change in repetition rate.
- the **BTY.STP-103** stopper, located at the booster extraction on the BTY line to ISOLDE: this is not part of LIU Project (K. Hanke personal communication). Moreover, due to its nature, a stopper is not affected by a change in repetition rate.
- the **H0/H- dumps** at Booster injection: these new devices are already being designed for a maximum repetition rate of 1.11 Hz (900 ms). This device should belong to Chapter **Error! Reference source not found.**.
- the **Head and Tail dumps**: these new devices are already being designed for a maximum repetition rate of 1.11 Hz (900 ms). This device should belong to Chapter **Error! Reference source not found.** too.

7.1 Equipment limiting the cycling rate (old and new)

The PSB dump is the only equipment that could limit the operation with 900 ms period. At the actual state of the development, there is certainly an impact in changing the period length, since :

- the total average deposited power will increase proportionally, and
- the fatigue life of the dump core will proportionally be shorten

7.1.1 Total average deposited power

The new PSB extraction dump is in design already, based on a pulsed beam of 1.4 and/or 2GeV with period *T* = 1.2s, a maximum intensity of 1E14 p+/pulse and a pulse length of 1.66 μs. These parameters make up a maximum average power of

$$\bar{P} = E \cdot \bar{I} = E \cdot I^{*} \cdot duty = 2 \cdot 10^{9}\,[eV] \cdot 1.602 \cdot 10^{-19}[C/p^{+}] \cdot 10^{14}[p^{+}/pulse] \cdot 1/1.2\,[pulse/s] =$$
$$= 26.7 \text{ kW}$$

where *E* is the beam energy, $\bar{I}$ is the average current [A], I^{*} the pulse current and *duty* is the rate between pulse length τ [s] and period length *T* [s].
The dump is designed to be able to continuously adsorb this average power with an acceptable steady temperature and stresses, with particular regards to its fatigue life and cooling, and in such a way that the almost instantaneous deposited power does not compromise in any way its functionality.
For a pulse period of 900 ms the average deposited power is increased by 33%, to a total value of 35.6 kW.

The design today under development does not allow this increased power to be adsorbed continuously and safely, since a much lower safety margins would be employed in operation, with consequent risk of failure.
Especially the steady state temperature developed in the dump inner core would be high enough to risk to cause a drastic change in the mechanical properties of the core material.

7.1.2 Fatigue life of the dump core

The dump inner core, which is the component which will most strongly suffer of fatigue and radiation damage at high temperature, is nowadays foreseen to be built in aluminium, the specific Al alloy still to be chosen.
Al alloys have limited fatigue strength at high temperature and radiation damage is reported in literature. A detailed analysis has still to be carried out, but some guidelines could be drawn already.
With a change (increase) in the repetition rate, the dynamic stresses which involve a limited fatigue lifetime would not increase in intensity, but a higher number of total fatigue cycles can be expected and a higher total number of accumulated proton will have to be considered for the radiation damage calculation.
At this regard, a detailed functional specification has not been produced yet. With the maximal and unlikely assumption of continuous 24h/day, 365 days/year operation, and a dump lifetime of 20 years, the 1.2s pulse period would make up for a number of fatigue cycles and of protons of :

$$NC_{1.2} = 1/1.2\,[cycle/s] \cdot 3600[s/h] \cdot 24[h/day] \cdot 365[day/year] \cdot 20[year] = 5.3 \cdot 10^{8}\ cycles$$

$$NP_{1.2} = NC_{1.2}[cycle] \cdot 10^{14}[p^{+}/cycle] = 5.3 \cdot 10^{22}\ protons$$

while with T = 900ms this numbers become $NC_{0.9} = 7 \cdot 10^{8}$ and $NP_{0.9} = 7 \cdot 10^{22}$ which represents again 33% of increase.
With this numbers in mind, the 33% increase does not make much difference since the fatigue elbow (number of cycles beyond which lifetime can be considered infinite when stresses are lower than the fatigue limit) is usually already reached at $NC = 10^{7} \div 10^{8} cycles$, and radiation damage due to the accumulated number of protons may be important already at $NP = 10^{21}\ protons$

7.2 Modifications needed to make existing equipment compatible with 900 ms operation and associated additional cost

None.

7.3 Modifications needed to make new equipment compatible with 900 ms operation and associated additional cost

The design under development of the new PSB dump would need to be reviewed, and a change in the design concept would probably be needed. At least an additional 20 kchf should be foreseen for the implementation of this change with the Design Office.

The main issue is the timing, since the design of the new dump must be ended soon and detailed by summer 2012. Material procurement has to be started by 1st July 2012.

7.4 900 ms for all cycles vs. 900 ms for LHC cycles only: difference in workload and cost

This would depend on the assumptions to be made on "how many LHC cycles goes onto the PSB dump in % over all".

8. Injection Equipment [Weterings et al]

The injection equipment concerned, old and new, are the following; BI.DIS, BI.SMV, BI.SMH, BI.BSW, BI.STR, and BI.KSW. The Head & Tail dumps as well as H^0/H^- dumps are covered in chapter 6.

8.1 Equipment limiting the cycling rate (old and new)

There will be no equipment limiting 900 ms operation. Nevertheless, it should be noted that the lifetime of the stripping foil BI.STR and septa BI.SMV will be lower at higher repetition rates. This also applies to the thyratron lifetime in systems where these devices are used (BE and BT KFAs).

8.2 Modifications needed to make existing equipment compatible with 900 ms operation and associated additional cost

All equipment has been tested successfully in 2005 at 900 ms operation. The only issue observed was vacuum degradation of the BI.SMV, probably due to heating and out-gassing of the internal Head and Tail dumps.

8.3 Modifications needed to make new equipment compatible with 900 ms operation and associated additional cost

All new equipment is designed to be compatible with 900 ms operation, which was the baseline when the injection work package was still included in the Linac4 project.

8.4 900 ms for all cycles vs. 900 ms for LHC cycles only: difference in workload and cost

No difference in workload or cost.

8.4.1 [LEVEL 3 TITLE]

8.4.1.1 [LEVEL 4 TITLE]

9. Extraction Equipment and PS Transfer Line [Borburgh et al]

The extraction and recombination equipment concerned, old and new, are the following; BE.KFA14, BE.SMH, BT.SMV10, BT.KFA10, BT.SMV20, BT.KFA20.

9.1 Equipment limiting the cycling rate (old and new)

There will be no equipment limiting 900 ms operation. Nevertheless, it should be noted that the lifetime of the thyratrons for the KFA's and septa will be lower at higher repetition rates.

9.2 Modifications needed to make existing equipment compatible with 900 ms operation and associated additional cost

The equipment is compatible with 900 ms operation.

9.3 Modifications needed to make new equipment compatible with 900 ms operation and associated additional cost

All new equipment is designed to be compatible with 900 ms operation. As a function of the lifetime of the equipment (related to the number of pulses per year) it may be required to construct an additional spare for BESMH, BT.SMV10 and BT.SMV20.

9.4 900 ms for all cycles vs. 900 ms for LHC cycles only: difference in workload and cost

No difference in workload or cost.

10. Controls, Timings [Jensen]

10.1 Equipment limiting the cycling rate (old and new)

xxx

10.2 Modifications needed to make existing equipment compatible with 900 ms operation and associated additional cost

xxx

10.3 Modifications needed to make new equipment compatible with 900 ms operation and associated additional cost

xxx

10.4 900 ms for all cycles vs. 900 ms for LHC cycles only: difference in workload and cost

xxx

10.4.1 [LEVEL 3 TITLE]

10.4.1.1 [LEVEL 4 TITLE]

11. Electrical Systems [Bozzini,Olek]

In case there is increased need for electrical power; if not, skip this section.

11.1 Equipment limiting the cycling rate (old and new)

xxx

11.2 Modifications needed to make existing equipment compatible with 900 ms operation and associated additional cost

xxx

11.3 Modifications needed to make new equipment compatible with 900 ms operation and associated additional cost

xxx

11.4 900 ms for all cycles vs. 900 ms for LHC cycles only: difference in workload and cost

xxx

11.4.1 [LEVEL 3 TITLE]

11.4.1.1 [LEVEL 4 TITLE]

12. Cooling and Ventilation [Nonis]

In case there is increased need for cooling; if not, skip this section.

12.1 Equipment limiting the cycling rate (old and new)

xxx

12.2 Modifications needed to make existing equipment compatible with 900 ms operation and associated additional cost

xxx

12.3 Modifications needed to make new equipment compatible with 900 ms operation and associated additional cost

xxx

12.4 900 ms for all cycles vs. 900 ms for LHC cycles only: difference in workload and cost

xxx

12.4.1 [LEVEL 3 TITLE]

12.4.1.1 [LEVEL 4 TITLE]

13. Interlocks [Puzzio]

In There will be no impact for the Beam Interlock System:

- The BIS is far faster than the cycle rate and will not limiting it to 1.2s.

In the other hand, the User Systems (connected to the BIS) have to take care of synchronization.

There will be no impact for the Warm Magnet Interlock System.

- The protection of the magnets from overheating by switching off the power converter is inherently independent of the cycle rate.

In both cases, the Interlock systems are brand new; neither new equipment nor upgrading will be needed.

14. Cost Summary [Hanke]