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THE CONSOLIDATION OF THE INTERLOCK SYSTEMS FOR THE CERN NORTH AREA

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Abstract

The interlock systems of the CERN North Experimental Area will be consolidated in CERN's Long Shutdowns 3 and 4, planned to start in 2026. The new interlock systems will guarantee the safe and efficient operation of the machine protection systems for the coming 25 years. The consolidation work includes not only the primary beam areas but also the secondary beam lines and possible new beam lines, as part of the Physics Beyond Colliders program.

This contribution describes the limitations of the present North Area interlock systems in terms of reliability and response and gives the details of the proposed new interlocking systems based on CERN standard hardware: the Warm Magnet Interlock Controller (WIC) and the Beam Interlock System (BIS). The WIC protects the resistive magnets against overheating and interfaces with the power converters and the BIS. The BIS collects operational information from many different systems. It will be SPS machine cycle dependent and will act on the beam dump system in the SPS and on the beam intercepting devices in the North Area beam lines.

INTRODUCTION

The CERN North Experimental Area beam lines cover approximately 6.3 kilometres from the Super Proton Synchrotron (SPS) to the experimental halls EHN1, EHN2 and ECN3 [1]. Several interlock systems are currently installed to protect the machine. The interlocks will be renovated in two phases during CERN's Long Shutdowns 3 and 4 as part of the North Area Consolidation project originally proposed at the CERN's 2016 Chamonix Workshop [2].

The North Area beam lines are fed with a high-intensity proton or ion beam that is slow extracted from the SPS ring by the means of four extraction sextupoles used to put the beam in resonance, nine bumpers to control the trajectory of the beam and three septa (one electrostatic and two magnetic) to divert the beam towards the TT21 transfer line. The TT21 transfer line is split into two sections separated by a Beam Intercepting Device (BID) called TED that can be moved in or out of the beam. The beam covers approximately one kilometre before being split into four primary beam lines TT22, TT23, TT24 and TT25. Three primary target stations (T2, T4, T6) produce secondary beams towards EHN1, EHN2 and ECN3. There is no BID that can be used for machine protection between the TT21 TED and the targets. The layout of the North Area is presented in Fig. 1.

Each secondary beam line has two BIDs called TAXes that can be inserted in the beam to protect the downstream beam line in case of equipment failure. The secondary beam lines can be split into three groups:

- H2, H4, H6 and H8 use secondary particles produced by T2 and T4 and lead to EHN1
- P4, P4:6, P42, K12 use secondary particles produced by T4 and lead to ECN3
- M2 uses secondary particles produced by T6 and lead to EHN2

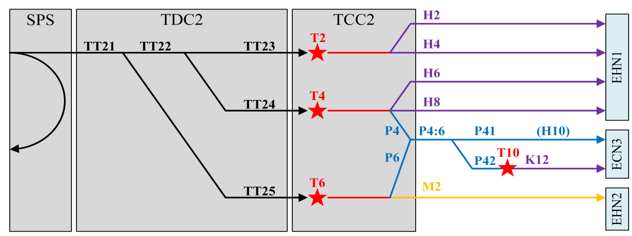

Figure 1: North Area beam lines.

LIMITATIONS OF THE CURRENT INTERLOCK SYSTEMS

There is currently no dedicated interlock system inhibiting the slow extraction of the beam from the SPS to the North Area. Nevertheless, several interlocks in the TT21 line are already connected to the SPS BIS. These include Beam Loss Monitors, TED position, vacuum valves and septa status. If an interlock is raised, then the BIS requests a beam dump in the SPS regardless of the beam destination, therefore stopping all operation in the SPS. This limitation is currently overcome by changing the configuration of the SPS cycle to remove the North Area destination and manually masking the TT21 interlocks. This error-prone intervention takes time, hence reducing the availability of the SPS.

In addition, several interlocks in the North Area primary and secondary beam lines are currently implemented in software. The SPS Software Interlock System (SIS) acts on the SPS BIS to request the beam to be dumped. The SIS inspects data that is sent periodically by the control systems, therefore leading to a potentially high latency. One incident occurred in July 2022 where one wobbling magnet of the T2 target station suddenly tripped. The SIS did not inhibit the beam before the end of the SPS cycle, leading to significant damage to target station instrumentation and loss of availability for the North Area.

One hardware-based interlock system is currently implemented to protect the P42 and K12 beam lines. This system checks that the current of all bending and important quadrupole magnets are within tolerance with respect to their beam reference. It also monitors the cooling of the T10

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target and K12 TAXes and the position of the vacuum valves in K12. Unfortunately, this system only protects a fraction of all the North Area beam lines.

The access system detects intrusions in all locations from the SPS ring to the North Area experimental halls. At present, if an interlock is raised by the access system, the septa magnets in TT21 are discharged to prevent the beam from going to the North Area and protect personnel. If a slow extraction is in progress, this could potentially lead to a particle shower and damage the equipment.

To protect magnets from overheating, the present magnet interlock system groups up to eight magnets in series to provide a single interlock signal to the corresponding power converter. In case of magnet failure, the power converter trips but does not directly provide an interlock to dump the beam in the SPS. Furthermore, the lack of individual magnet diagnostics leads to potentially long interventions in areas submitted to high radiations.

BEAM INTERLOCK SYSTEM

The BIS is a fundamental part of the systems used to protect the CERN accelerators against possible damage from beam impact. Numerous controllers are distributed throughout the CERN accelerator complex. They are designed to very high standards and must be proven to operate with the required high levels of reliability and availability. The new version of the BIS is currently being developed and will be deployed at the LHC, SPS and North Area during CERN's Long Shutdown 3 [3].

Interlocking architecture

The architecture of the BIS for the North Area is composed of nine Beam Interlock Controllers (BIC) and is presented in Fig. 2.

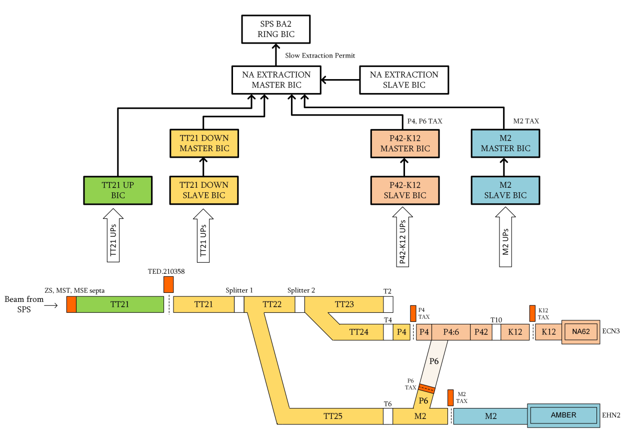

Figure 2: Architecture of the BIS for the North Area [4].

The BIS considers four interlocking zones:

- TT21 Upstream between the SPS and the TT21 TED
- TT21 Downstream for the beam lines from the TT21 TED up to the secondary line P4 and M2 TAXes
- P42-K12 from the P4 TAX down to ECN3
- M2 from the M2 TAX down to EHN2

It has to be noted that the beam lines that lead to EHN1 (H2, H4, H6, H8) are not protected by the BIS due to a less severe risk of damaging the equipment. This results from a risk analysis done by the North Area users.

These four zones will be protected by slave BICs that will provide permits to a master extraction BIC (named NA EXTRACTION MASTER BIC in Fig. 2). The master extraction BIC will be responsible for allowing or inhibiting the slow extraction of the beam to the North Area. For this purpose, it will implement a matrix of equations to control the permit given to the existing SPS ring BIS. These equations include the status of the slave BICs as well as the status of all the systems required to safely extract the beam, for example the extraction sextupoles and bumpers, the position of the BIDs, and the current monitoring interlock of the TT21 main dipole string.

Another critical aspect of the extraction BIC is its dependence on the beam destination provided by CERN's timing network. For beam destinations other than the North Area, the extraction BIC will provide the permit to the SPS ring BIS if all extraction sextupoles and bumpers are at minimum current. In this case, the interlocks further down the line are not taken into account. This will considerably increase the availability of the SPS because it will allow all other SPS destinations, e.g. AWAKE, HiRadMat or the LHC, to continue unaffected in case of unavailability of the North Area.

The BICs protecting the P42-K12 and M12 interlocking zones will also control the position of the P4 and M2 TAXes respectively. If an interlock is raised in the P42 beam line, then the BIS requests the P4 TAX to be moved in-beam. While the TAX is moving, the BIS inhibits the slow extraction to the North Area. Once the TAX is fully in the in-beam position, the operation to the North Area can resume.

Beam Interlock System users

The BIS collects interlocks provided by a great variety of user systems. These include: power converters' current monitoring, warm magnet protection systems, beam loss monitors, vacuum valves, beam intercepting devices, septa and the access system.

The number of user connections per system type is presented in Table 1. This table only lists the connections to the BIS. Each input can group several systems: for example there are 28 Power converter inputs to the BIS grouping 142 Power converters in total.

Interlock masking

Under specific operational conditions, the operators might need to mask several interlocks. This is the case for example for the current monitoring of the power converters or the beam loss monitors. Nevertheless, masking interlocks in the BIS will only be permitted with a low intensity beam, for example during machine set up.

The Safe Machine Parameter (SMP) is a system that complements the BIS by providing flags that allow the masking of certain interlocks under set-up beam conditions [5]. The

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Table 1: Number of User Inputs Per System Type

System	Number of inputs
Power converters	28
Warm magnet interlock systems	11
Septa	2
Beam intercepting devices	17
Access system	3
Vacuum valves	4
Beam loss monitors	3
Total	**68**

SMP will provide a dedicated North Area Flag to the BIS that will indicate if the beam intensity in the SPS is lower than 5×10^{12} protons. Only in this case, the BIS allows masking a few specific interlocks.

During machine set up, beam intensities of up to 2×10^{12} protons are used to configure the machine. In normal operation, the beam intensity in the SPS is about 3×10^{13} protons. The intensity threshold of 5×10^{12} protons guarantees that the inputs will only be maskable during machine setup and not during normal operation.

High-Intensity facility at ECN3

The interlocking plan considers the possible implementation of the High-Intensity facility at ECN3 [6]. If approved, this project will need the introduction of a dedicated user to determine which cycle-type is being played. The cycle-type would need to be an input to the extraction BIC's matrix.

In addition, new interlock inputs might have to be connected to the BIS. Thanks to its distributed topology, the BIS for the North Area eases the addition of new inputs by reducing the cable length between the user systems and the BICs. Finally, any addition of inputs has no impact on the performance of the BIS.

WARM MAGNET INTERLOCK SYSTEM

The Warm Magnet Interlock Controller system (WIC) protects the normal-conducting magnets from overheating by switching off the corresponding power converter when a magnet cooling fault occurs. It is the standard magnet protection system deployed throughout the CERN accelerator complex. Furthermore, the WIC is capable to send a beam inhibit request to the BIS [7].

The WIC is also capable of reporting the Power Converter's status when it is equipped with FGC-type controls. When the Power Converter reports an internal fault, the WIC can optionally raise an interlock to the BIS.

The architecture of the WIC for the North Area is composed of seven WICs and is presented in Fig. 3. The WIC deployment will follow the power converter renovation, therefore the WIC systems in BA2 and BA80 will be deployed in LS3 and the remaining systems in BA81 and BA82 in LS4. The number of connections to the WIC is presented in Table 2.

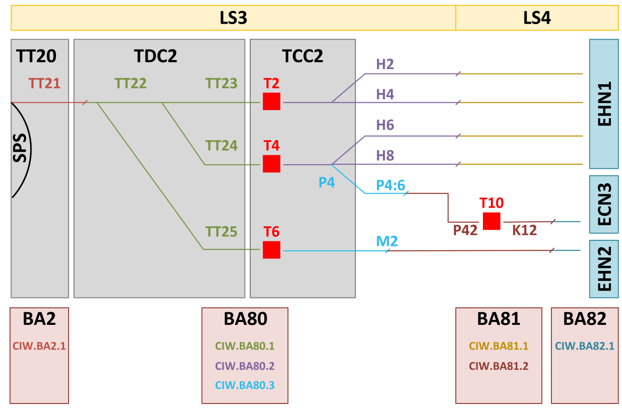

Figure 3: Architecture of the WIC for the North Area.

Table 2: Number of Connections to the WIC

Type	LS3	LS4	Total
Power converters	180	190	370
Magnets	300	250	550
Water cooled DC cables	45	64	109

Unlike the BIS, the WIC will also protect the magnets of the H2, H4, H6, H8 beam lines from overheating.

Each magnet of the North Area will provide one interlock to the WIC. The fault detection and diagnosis will be greatly improved, hence reducing the intervention time and the doses taken by personnel (ALARA principle).

CONCLUSIONS

The consolidated interlocking system for the North Area addresses the current limitations of the machine protection systems currently deployed in the primary and secondary beam lines. It will be based on the BIS and the WIC which are standard interlock systems deployed throughout the CERN accelerator complex with a proven record of very high reliability and availability. The proposed architecture of these systems is distributed across all North Area beam lines and surface buildings, hence allowing the future addition of interlocks especially in the context of the possible High-Intensity facility at ECN3.

The North Area consolidation foresees the deployment of the interlocking systems in two phases during CERN's Long Shutdowns 3 and 4 with the first beam planned for 2028.

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