ZHAW – Institute of Applied Mathematics and Physics (IAMP)

Fast Beam Interlock System (FBIS)

Concept of Operations

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Table of Contents

1 Introduction

1.1 Scope

This document describes the Fast Beam Interlock System (FBIS) behavior from a functional viewpoint of an end-user. It neither describes the architecture of the FBIS nor the realization of the FBIS functionality. Where necessary this document states explicit assumptions on other systems and their assumed behavior. A list of all assumptions is provided in Appendix I.

1.2 Purpose

This document explains how the FBIS will behave as part of ESS Machine Protection in the context of ESS operation. The document is intended for a general audience and should enable an early review of operational concepts before entering the FBIS technical requirements specifications phase.

1.3 Definitions and Acronyms

For further definitions and acronyms see the Machine Protection Glossary [4]

Ref	Term	Definition
1	Beam Inhibit	A function performed by the FBIS which inhibits further generation of proton beam pulses.
2	BEAM-PERMIT	A binary signal generated by MP-related Systems. An MP-related System sets a BEAM-PERMIT output to the value OK if it does not see any reason to prevent beam. Otherwise, it sets the BEAM-PERMIT output to the value NOK (Not-OK). BEAM-PERMIT signals are typically latched by the FBIS as they are not expected to switch to NOK during normal operation.
3	Emergency Beam Interlock	A function performed by the FBIS similar to the Regular Beam Interlock but making use of additional Actuation Systems.
4	Enforced Proton Beam Destination	Proton Beam Destination used as a reference by MP-related Systems when performing their MP-related Functions.
5	Enforced Proton Beam Mode	Proton Beam Mode used as a reference by MP-related Systems when performing their MP-related Functions.
6	Functional Readiness	The property of a system to be ready for performing its intended function upon demand.
7	Hazardous State	State that might lead to unacceptable damage and activation risks for the Machine.
8	Higher-Level Control Systems	Systems which control the behavior of the FBIS and other ESS systems. EPICS can be seen as part of the Higher-Level Control System.
9	Requested Proton Beam Destination/ Proton Beam Mode	Proton Beam Destination/Proton Beam Mode the machine is requested to be configured for. The Requested Proton Beam Destination/Proton Beam Mode is broadcasted to all relevant systems by the ESS Timing System.
10	Interceptive Device	Device that can be inserted into or extracted from the beam-pipe. Interceptive Devices include for example Faraday Cups, Beam Stops, Emittance Measurement Units, and Wire Scanners.

11	Intermediate Proton Beam Destination	A Proton Beam Destination different than the Target and Tuning Dump. An example for an intermediate proton beam destination is the Faraday Cup in the DTL beamline section.
12	Machine	In the context of ESS Machine Protection, the term “machine” encompasses all elements in the Accelerator, Target Station and Neutron Science system segments; all being necessary for neutron beam production and its further use by the neutron science experiments.
13	Machine Protection related Function (MP-related Function)	A function that contributes to a Protection Function.
14	Machine Protection related System (MP-related System)	System involved in the protection of the machine. An MP-related system is characterized through the following. It both: (a) implements MP-related functions or complete Protection Functions; and (b) is intended to achieve the necessary protection integrity for the required machine protection functions - on its own or with other MP-related systems and other damage risk reduction measures.
15	Machine Protection System-of-Systems (MP-SoS)	The set of all MP-related systems.
16	MP-related Actuation System (Actuation System)	System which implements MP-related functions used to achieve and maintain a Protected State.
17	MP-related Sensor System	System that implements MP-related functions used to detect a state that might lead to unacceptable damage or activation of the machine.
18	Protected State	State in which the Machine is free from unacceptable damage and activation risks.
19	Protection Function	Function which is intended to achieve or maintain the Protected State for the Machine, in respect of a specific hazardous state. Protection functions are implemented by MP-related systems.
20	Proton Beam Destination	Information specifying either a Faraday-Cup, the Tuning Dump or the ESS Target as being the final destination for the beam.
21	Proton Beam Mode	Information specifying limits for single or for combinations of beam parameters, e.g. beam current, beam pulse length, pulse repetition rate, etc.
22	READY	A binary signal generated by MP-related Systems. An MP-related System sets a READY output to the value OK if it does not see any reason to prevent beam. Otherwise, it sets the READY output to the value NOK (Not-OK). READY signals are typically not latched by the FBIS as they are expected to switch to NOK during normal operation. For example while a MP-related System re-configures to enforce a new Proton Beam Destination.
23	Regular Beam Interlock	A function performed by the FBIS which inhibits further generation of proton beam pulses and causes the proton beam to be dumped.
24	System Health	Condition of a system indicating whether the system performs within its specifications.

2 References

Ref	Title	Version or Date
1	Machine Protection – System Requirements and Architectural Framework (CB:248501 version 1)	Revision 1 from 29.11.2015
2	MP Beam Interlock System – System Requirements Specification (CB:248500 version 1)	Revision 1 from 11.6.2015
3	ESS Beam Interlock System – Architecture Concepts (CB:261557 version 3)	Revision 1A from 18.03.2016
4	Machine Protection Glossary ESS-0124263	Revision 2 from 03.08.2017

3 Role of the Fast Beam Interlock System

The FBIS is part of the Machine Protection (MP) System-of-Systems [1] [2]. In essence (see Figure 1) the FBIS constitutes the final link between systems that might request to achieve and maintain the Protected State and the MP-related Actuation Systems (referred to as “Actuation Systems”). The systems requesting to achieve and maintain the Protected State include all MP-related Sensor Systems.

The FBIS controls the Actuation Systems to achieve and maintain the Protected State based on a customizable decision logic and the following information:

- All relevant information from the MP-related Systems connected to the FBIS. This includes BEAM-PERMIT signals, READY signals, operational status information, health status information, and others as applicable;
- the selected proton beam destination and proton beam mode of the Machine;
- the proton beam destination and proton beam mode configuration of all relevant MP-related Systems;
- “no-beam detected” information from MP-related Sensor Systems monitoring the proton beam;
- Interceptive Device positions.

The FBIS decision logic cannot be changed while the FBIS is in operation.

The FBIS interfaces to the ESS Timing System and Higher-Level Safety and Control Systems as needed for setup, configuration, and diagnostic purposes.

Figure 1 follows the illustration of sensor system, logic system, and actuation system from left to right with horizontal arrows as adopted in functional safety standards such as IEC 61508. The bi-directional arrow between the FBIS and Actuation Systems indicates that the status of the Actuation System is read-back by the FBIS.

The Higher-Level Safety System and Higher-Level Control Systems may request the FBIS to switch-off beam as well. Therefore the two arrows from each of them to the FBIS. Likewise the ESS Timing System plays a dual role: As Actuation System and as system providing triggers and information about the requested state of the machine.

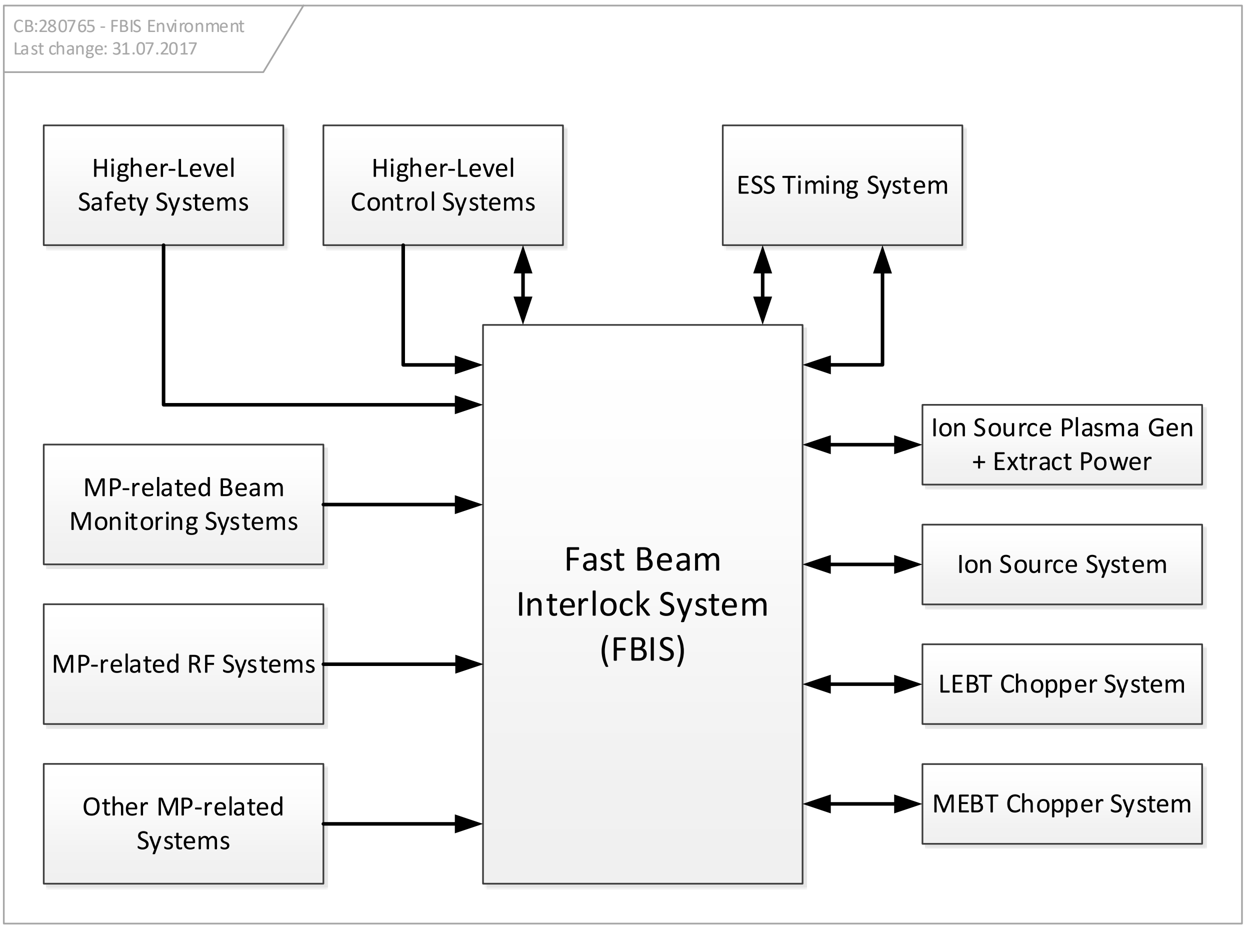

Figure 1: Simplified overview of the FBIS environment showing MP-related Actuation Systems (right), MP-related Systems providing inputs to the FBIS (left) and higher level systems (top). Only the systems that are explicitly mentioned in this document are shown on the diagram.

3.1 Embedding the FBIS in Machine Protection

The reaction time[1] required from Machine Protection related Functions varies over several orders of magnitude. For example, it might be acceptable to switch-off beam within milliseconds upon detection of an unexpected status from a mechanical end-switch, due to the inertia of mechanical devices. However, if unanticipated beam-losses are detected, a transition to the Protected State might be required to happen in the order of micro-seconds (µs) to prevent damage.

While slow reaction times, in the order of milliseconds, can be managed by standard off-the-shelf PLC based equipment, we currently assume that custom components will be needed to manage reaction times of the order of µs. The qualifier "fast" has been added to highlight that the FBIS will be capable to cope with these demanding reaction times. However, this does not imply that there exists an explicit "Slow Beam Interlock System".

We assume that the FBIS directly interfaces with the Actuation Systems for Machine Protection purposes[2]. As at least some of the Actuation Systems feature only one input for Machine Protection purposes, we further

[1] The time between detection of a situation, that might lead to damage and of achieving the safe state.
[2] No additional latency is introduced by routing the signal via other systems.

assume that PLC based systems do not directly interface with the Actuation Systems. Instead, the aggregated beam switch-off requests from PLC based systems will be fed as inputs to the FBIS[3].

4 Behavior of the FBIS

4.1 General Behavior of the FBIS

The FBIS acts as an observer. It only reacts when it detects a deviation of its inputs from the expected state or when it detects an FBIS internal inconsistency or failure.

To perform its function, the FBIS relies on external systems providing specific information. We assume that:

- the FBIS receives the necessary information from the ESS Timing System to differentiate between phases when beam is expected and when no beam is expected;
- the FBIS receives dependable information from MP-Related Beam Monitoring Systems whether proton beam is present directly downstream of intermediate beam destinations as defined by the proton beam destination;
- the FBIS receives dependable information from MP-Related Systems whether beam is present directly at the exit of the Ion Source;
- the FBIS receives dependable information from MP-Related Systems whether the Ion Source is successfully interlocked or not; Interlocking the source is equivalent to switching off plasma generation;
- the FBIS receives dependable status information from the LEBT and MEBT choppers to determine whether the beam is deflected or not.

The reaction of the FBIS to an unexpected input state depends (a) on the configuration of the respective FBIS input and (b) on the status of the proton beam.

a) An FBIS input can either be configured to “no latching” or to “latch NOK” (see also Figure 2):

- If an FBIS input is configured to no latching the signal is processed as detected at the FBIS input.
- If an FBIS input is configured to latch NOK, a NOK state is latched until an explicit reset occurs.

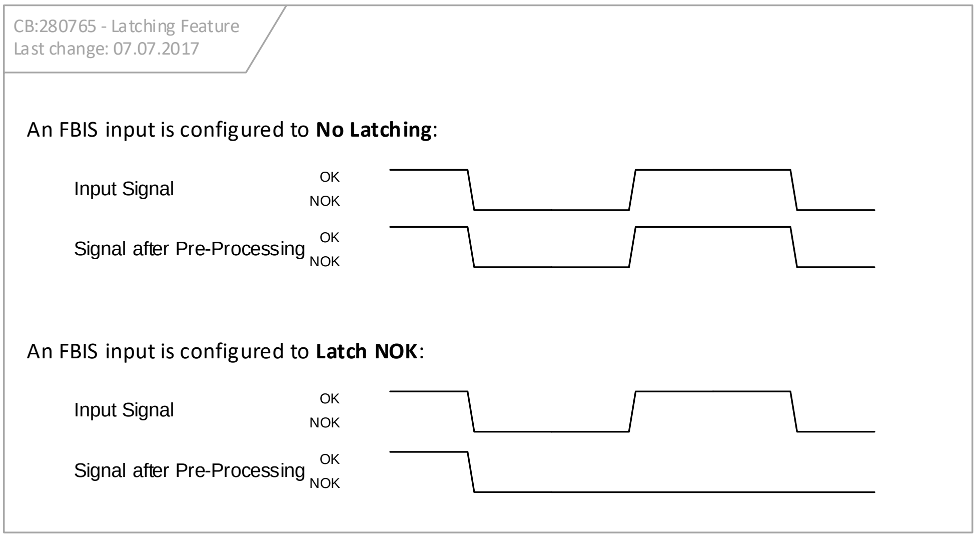

Figure 2: An FBIS input can be configured to “no latching” or to “latch NOK”. If an input is configured to latch NOK the NOK state is latched until an explicit reset occurs.

[3] The PLC based systems have the possibility to request a beam switch-off but cannot influence the switch-off sequence and escalation strategy. The switch-off sequence and escalation strategy (see chapter 5) is defined by the FBIS.

The configuration of FBIS inputs with respect to latching is part of the decision logic and cannot be modified while the FBIS is in operation.

b) The proton beam can have two states (see also Figure 3):

- The proton beam can be off, for example in between two proton beam pulses. This phase is referred to as inter-pulse phase.
- The proton beam can be on. This phase is referred to as intra-pulse phase[4].

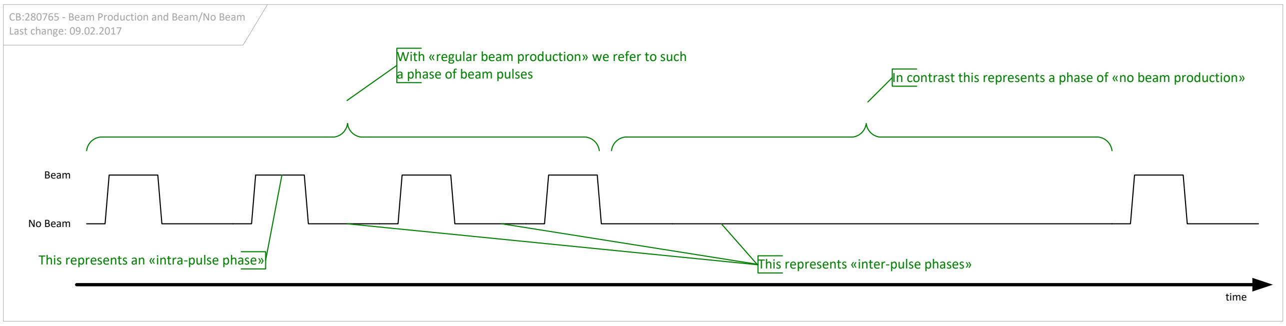

Figure 3: Definition of the terms “regular beam production”, “intra-pulse phase” and “inter-pulse phase”.

Table 1: Summary of the FBIS reaction to an input signal in state NOK.

Proton Beam state	Configuration of the FBIS Input	FBIS reaction to an input signal in state NOK
Inter-pulse phase	No latching (READY signal)	The FBIS carries out a “Beam Inhibit”. The “Beam Inhibit” is not latched.
	Latch NOK (BEAM-PERMIT signal)	The FBIS carries out a “Beam Inhibit”. The “Beam Inhibit” is latched. Additionally: The FBIS informs the ESS Timing System that the Beam Inhibit is latched.
Intra-pulse phase	No latching (READY signal)	The FBIS carries out a “Regular Beam Interlock”. The “Regular Beam Interlock” is latched. Additionally: The FBIS informs the ESS Timing System that the Regular Beam Interlock is latched.
	Latch NOK (BEAM-PERMIT signal)	

4.1.1 Beam Inhibit Generation

When carrying out a “Beam Inhibit” the FBIS performs the following actions:

[4] No unified terminology referring to beam states is established at ESS. Due to the absence of better terms, throughout this document the terms “intra-phase” and “inter-phase” will be used although their spelling is very alike.

- it inhibits the generation of further beam pulses by acting on the ESS Timing System;
- it interrupts proton beam extraction by “interlocking” the Ion Source through a dedicated input of the Ion Source System;
- in addition, it activates the LEBT and MEBT choppers as precaution, should the inhibit via ESS Timing System and Ion Source System fail.

When the Beam Inhibit is the reaction to an OK to NOK transition of an input configured to “no latching” the Beam Inhibit is removed automatically as soon as the respective input switches back to OK. No external reset is required. Figure 4 illustrates such a Beam Inhibit sequence: The FBIS performs the Beam Inhibit as soon as the Input Signal transitions from OK to NOK. Once the signal switches back to OK, the Beam Inhibit is removed.

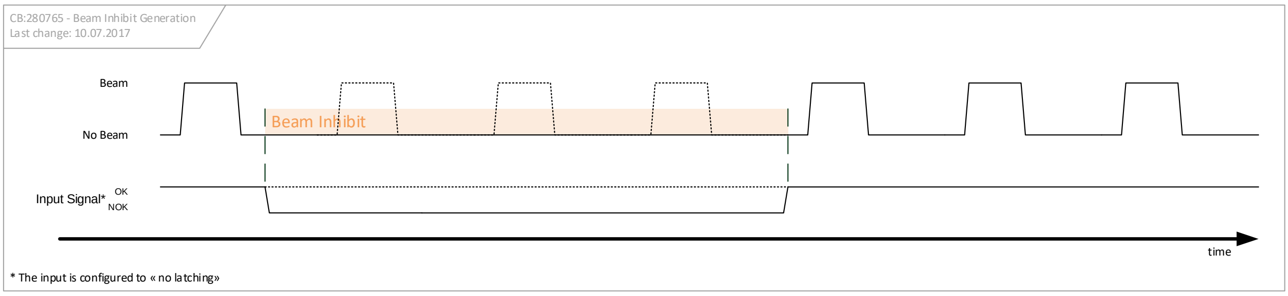

Figure 4: Illustration of a Beam Inhibit generation. The FBIS performs the inhibit as long as the Input Signal (configuration “not latching”) has the state NOK and removes the inhibit automatically once the Input Signal switches back to OK. The time during which the FBIS performs the Beam Inhibit is highlighted in orange. The dotted line represents the sequence resulting if the Input Signal would stay OK.

In contrast to above, Figure 5 illustrates the same sequence for an input signal configured to “latch NOK”. Again, the FBIS carries out a Beam Inhibit as soon as the Input Signal transitions from OK to NOK. However, the Beam Inhibit remains until externally reset, although the signal switches back to OK. The FBIS informs the ESS Timing System that the Beam Inhibit is latched.

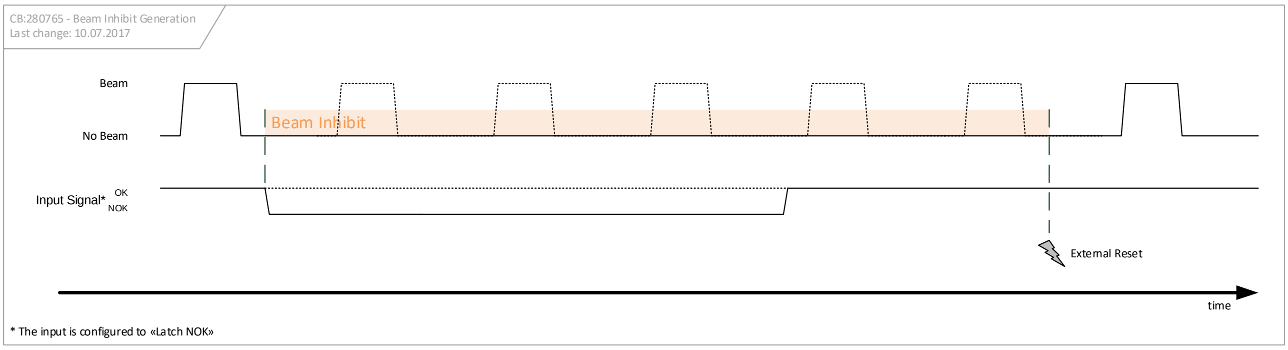

Figure 5: Illustration of a Beam Inhibit generation. The Beam Inhibit remains although the Input Signal (configuration “latch NOK”) switches back to OK. The Beam Inhibit is removed only after an external reset. The time during which the FBIS carries out the Beam Inhibit is highlighted in orange. The dotted line represents the sequence resulting if the Input Signal would stay OK.

The generation of a Beam Inhibit can also be requested via the Higher-Level Control System. This function is needed in order to smoothly change modes as described later in chapters 4.2 and 4.4.

4.1.2 Regular Beam Interlock Generation

When carrying out a “Regular Beam Interlock” the FBIS performs the following actions:

- o it inhibits the generation of further beam pulses by acting on the ESS Timing System;

- o it interrupts proton beam extraction by "interlocking" the Ion Source through a dedicated input of the Ion Source System;
- o causes the proton beam to be dumped by activating the LEBT and MEBT choppers.

In contrast to the Beam Inhibit, the Regular Beam Interlock persists always until reset from externally. Figure 6 illustrates a Regular Beam Interlock as reaction to an OK to NOK transition of an input signal. Note that the duration of the second proton beam pulse is shortened as the pulse is terminated by the interlock.

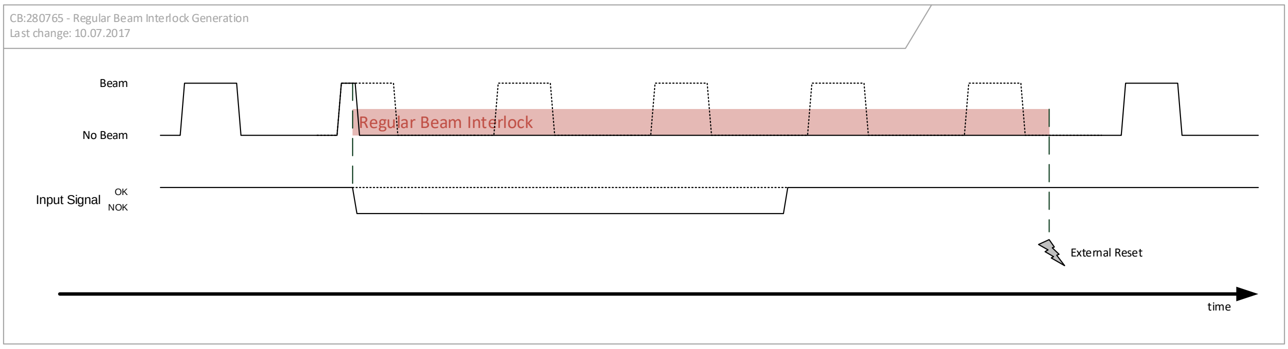

Figure 6: Illustration of a Regular Beam Interlock generation. The interlock persists until externally reset although the input signal switches back to OK before the reset. The time during which the FBIS carries out the Regular Beam Interlock is highlighted in red. The dotted line represents the sequence resulting if the Input Signal would stay OK.

For the Regular Beam Interlock it does not make a difference whether an input is configured to "no latching" or "latch NOK". The FBIS behavior is always the same.

4.1.3 Escalation and Emergency Beam Interlock

The FBIS checks whether the Beam Inhibit and Regular Beam Interlock functions have been successfully carried out by evaluating:

- information from the Ion Source System whether beam is being extracted (no beam with damage potential should be extracted;
- status feedbacks from the LEBT and MEBT choppers indicating whether they are deflecting the proton beam or not.

If the Beam Inhibit fails, the FBIS escalates to a Regular Beam Interlock.

If the Regular Beam Interlock fails, the FBIS escalates to an Emergency Beam Interlock by:

- cutting the power to the plasma generator of the Ion Source System and
- cutting the power to the extraction system of the Ion Source System.

4.1.3.1 Beam Presence Detection

If MP-related Beam Monitoring Systems signal that they detect beam during inter-pulse phases, the FBIS carries out a Regular Beam Interlock. The same is true if the Ion Source System signals that protons are being extracted during inter-pulse phases.

If after a certain timeout beam is still detected, the FBIS escalates the Regular Beam Interlock to an Emergency Beam Interlock.

4.2 Behavior during Proton Beam Destination Changes

The FBIS carries out a Beam Inhibit during a transition between proton beam destinations (e.g. from the DTL-FC to the Target).

To be able to perform this function, we assume that:

- the FBIS can determine the Requested Proton Beam Destination from information provided by the ESS Timing System;
- all relevant MP-related Systems communicate the Proton Beam Destination they are configured for to the FBIS.

The FBIS compares the Detected Proton Beam Destination with the Requested Proton Beam Destination it gets from the ESS Timing System. In case of an inconsistency, the FBIS carries out a Beam Inhibit or a Regular Beam Interlock depending on the state of the proton beam.

The sequence to change the proton beam destination is as follows:

- The Higher-Level Control System requests the FBIS to inhibit beam;
- The Higher-Level Control System initiates the proton beam destination change;
- While the systems re-configure for the requested beam destination, the FBIS will detect mode mismatches. However, as the FBIS inhibits beam anyways this does not result in further actions;
- Once the new destination has been successfully set, the FBIS detects consistent modes again. In other words: the Requested Proton Beam Destination has become the Enforced Proton Beam Destination;
- The request to do so from the Higher-Level Control System is the only reason why the FBIS still carries out a Beam Inhibit;
- As soon as the Higher-Level Control System removes the request, the FBIS allows beam again.

If the beam destination change would start while beam is on, the FBIS would immediately carry out a Regular Beam Interlock. As a consequence the operator would have to perform a reset. In order to avoid this, the first step of the sequence (requesting a beam inhibit via Higher-Level Control System) is recommended although not mandatory from a machine protection viewpoint.

4.3 Influence of Proton Beam Destination on the FBIS Behavior

Once an intermediate beam destination is set, the FBIS only considers signals and information relevant to systems upstream to this enforced beam destination. Any signals or information related to systems downstream this enforced beam destination will be ignored. For example, if beam is sent to the DTL-FC, then signals from systems in the target station can be ignored. The same is true for signals from systems in the cold LINAC for this example.

The following exception applies: the beam state right downstream the enforced beam destination, as well as all necessary conditions for a dependable measurement of that beam state, are checked. If beam is detected downstream the enforced beam destination, or if the conditions for that beam state measurement are not given, the FBIS carries out a Beam Inhibit or a Regular Beam Interlock depending on the beam state.

4.4 Behavior during Proton Beam Mode Changes

The FBIS carries out a Beam Inhibit during a transition between proton beam modes. (e.g. from probe beam to slow tuning).

To be able to perform this function, we assume that:

- the FBIS can determine the Requested Proton Beam Mode from information provided by the ESS Timing System;
- all relevant MP-related Beam Monitoring Systems communicate the Enforced Proton Beam Mode they are configured for to the FBIS.

Sequence and behavior of changing the Proton Beam Mode is analogous to changing the Proton Beam Destination as described in chapter 4.3.

4.5 Reaction to Beam Losses caused by Upstream Interceptive Devices

If MP-related Beam Monitoring Systems signal the detection of beam losses caused by inserting interceptive devices upstream the current beam destination, the FBIS will not react. An example for such devices are Wire Scanners and the Low Emittance Measurement Units.

To implement that logic, we assume that:

- the FBIS has access to dependable information about the actual position of all interceptive devices;
- the FBIS has access to the intended position of each interceptive device, as set in the control system;
- the FBIS receives information from MP-related Beam Monitoring Systems in such a way that it implement this logic[5].

4.6 Support for Degraded Mode Operation

The FBIS can be programmed to allow the masking of (a) external inputs or of (b) parts of the decision logic as a function of an internal ruleset. The ruleset may include for example requirements on the Enforced Proton Beam Destination and Enforced Proton Beam Mode. Masking will be available through the Higher-Level Control System interface. The FBIS will make information available to diagnose whether masking requests have been correctly propagated and fulfilled.

The FBIS will not support re-programming the ruleset of masking while in operation. (See also chapter 7)

5 Central FBIS Functions

5.1 Beam Inhibit Function

The Beam Inhibit Function:

- inhibits the generation of further beam pulses by acting on the ESS Timing System;
- interrupts proton beam extraction by “interlocking” the Ion Source through a dedicated input of the Ion Source System;
- activates the LEBT and MEBT choppers as precaution, if the Beam Inhibit via ESS Timing System fails.

The FBIS carries out a Beam Inhibit whenever one of the following conditions apply in between proton beam pulses (inter-pulse phase):

- a BEAM-PERMIT or READY signal switches to NOK;
- an inconsistency between the Requested and Enforced Proton Beam Destination is detected;
- an inconsistency between the Requested and Enforced Proton Beam Mode is detected;
- a malfunction of the LEBT- or MEBT-chopper or any other supervised MP-related system is detected.

Additionally, the FBIS carries out a Beam Inhibit when:

- a request to activate the Beam Inhibit function is received from the Higher-Level Control System.

The FBIS checks whether the Beam Inhibit function is successful by evaluating:

- whether the ESS Timing Systems actually stops triggering beam pulses;
- the proton beam state at the exit of the Ion Source;
- information from the Ion Source System whether beam is being extracted;

[5] This rules out for example the concentration of all beam loss measurements into one single BEAM-PERMIT signal.

- status feedbacks from the LEBT and MEBT choppers.

If the Beam Inhibit fails, the FBIS escalates to a Regular Beam Interlock.

If the Beam Inhibit is caused through an FBIS input configured to "no latching" the Beam Inhibit is removed automatically as soon as this input switches back to OK again. Otherwise the Beam Inhibit is latched until explicitly reset via the Higher-Level Control Systems.

5.2 Regular Beam Interlock Function

The Regular Beam Interlock function:

- inhibits the generation of further beam pulses by acting on the ESS Timing System;
- causes the proton beam to be dumped by means of the LEBT and MEBT choppers;
- interrupts proton beam extraction by "interlocking" the Ion Source through a dedicated input of the Ion Source System.

The FBIS carries out a Regular Beam Interlock whenever a Beam Inhibit fails or whenever one of the following conditions apply during a proton beam pulse (intra-pulse phase):

- a BEAM-PERMIT or READY signal switches to NOK;
- an inconsistency between the Requested and Enforced Proton Beam Destination is detected;
- an inconsistency between the Requested and Enforced Proton Beam Mode is detected;
- a malfunction of the LEBT- or MEBT-chopper or any other supervised MP-related system is detected.

Additionally, the FBIS carries out a Regular Beam Interlock when:

- a request to activate the Regular Beam Interlock is received from Higher-Level Control System;
- the checks confirming a successful Beam Inhibit have failed;
- MP-related Beam Monitoring Systems signal beam presence during inter-pulse phases.

The FBIS checks whether the Regular Beam Interlock function is successful by evaluating:

- whether the ESS Timing Systems actually stops triggering beam pulses;
- the proton beam state at the output of the Ion Source;
- information from the Ion Source System whether beam is being extracted;
- status feedbacks from the LEBT and MEBT choppers.

If the Regular Beam Interlock fails, the FBIS escalates to an Emergency Beam Interlock.

The Regular Beam Interlock is latched until explicitly reset via the Higher-Level Control Systems.

5.3 Emergency Beam Interlock Function

The Emergency Beam Interlock function:

- inhibits the generation of further beam pulses by acting on the ESS Timing System;
- causes the proton beam to be dumped by means of the LEBT and MEBT choppers;
- interrupts proton beam extraction by
    - "interlocking" the Ion Source through a dedicated input of the Ion Source System;
    - cutting the power to the plasma generator system of the Ion Source;
    - cutting the power to the extraction system of the Ion Source.

The FBIS carries out an Emergency Beam Interlock whenever a Regular Beam Interlock fails.

The FBIS checks whether the Emergency Beam Interlock function is successful by evaluating:

- the proton beam state at the output of the Ion Source;

- the power-state of the Ion Source plasma generation and extraction systems;
- status feedbacks from the LEBT and MEBT choppers.

If the Emergency Beam Interlock fails, the FBIS alarms the Higher-Level Control System.

The Emergency Beam Interlock is latched until explicitly reset via the Higher-Level Control Systems.

5.4 MP-SoS Configuration Consistency Check

One of the biggest risks in complex safety or protection systems is configuration confusion, i.e. when some parts of the system make wrong assumptions about the operational state of the equipment under control and draw wrong conclusions. This causes either spurious trips or unhandled hazardous states that can lead to damage. That is why mode consistency checks are required at the MP-SoS level.

The FBIS checks that the Proton Beam Destination and Proton Beam Mode are consistently set among all relevant MP-related systems.

5.4.1 Proton Beam Destination Consistency Check

We assume that all MP-related Systems that are using Proton Beam Destination information to perform their MP-related functions communicate the Proton Beam Destination they are configured for and are enforcing to the FBIS. Example: If the bending magnets are configured for the proton beam destination "Target" they power the respective magnets. The LPS-A2T takes care about these magnets and informs the FBIS whether they are configured for the proton beam destination "Target". If this configuration conflicts with the configuration of the rest of the facility, the FBIS ensures no beam is produced.

In case of an inconsistency between the mode information received, the FBIS carries out a Beam Inhibit or a Regular Beam Interlock. Whether a Beam Inhibit or a Regular Beam Interlock is carried out, depends on the beam state (see chapters 4.1.1 through 4.1.2).

5.4.2 Proton Beam Mode Consistency Check

We assume that all MP-related Systems that are using Proton Beam Mode Information to perform their MP-related functions, communicate the Proton Beam Mode they are configured for and are enforcing to the FBIS.

In case of an inconsistency between the mode information received, the FBIS carries out a Beam Inhibit or a Regular Beam Interlock. Whether a Beam Inhibit or a Regular Beam Interlock is carried out, depends on the beam state (see chapters 4.1.1 through 4.1.2).

5.5 Health Monitoring of MP-related Systems

The FBIS monitors whether relevant MP-related Systems are still operating within their specifications. For this purpose, we assume that the relevant systems will communicate health status information as well as a dynamic heartbeat signal, proving their correct functioning, to the FBIS. In case an MP-related Systems health cannot be assured, the FBIS carries out a Beam Inhibit or a Regular Beam Interlock, depending on the beam state.

We assume that all relevant MP-related Systems will provide health information within acceptable time and with adequate information content.

5.6 FBIS Self-Diagnostics

The FBIS continuously monitors its own health state. In case a problem is detected, the FBIS carries out a Regular Beam Interlock.

Depending on the situation and the cause of the problem the operator may be allowed to resume beam production in a degraded mode with certain functionalities of the FBIS masked or turned off.

5.7 Functional Readiness Monitoring of MP-related Actuation Systems

The FBIS monitors whether MP-related Actuation Systems are ready to perform their intended function upon demand. In case an Actuation System is not functionally ready, the FBIS carries out a Beam Inhibit or a Regular Beam Interlock, depending on the beam state.

The functional readiness of a system should not be confused with the health status of a system. A system can be fully healthy, i.e. operating within its specifications, even when not being functionally ready. Examples include systems that need to reload capacitors in order to be functionally ready, and where the reloading of the capacitors is part of the systems normal operation.

5.8 MP-related Actuation System Interfacing and Control Sequence

The typical sequence to activate an Actuation System is the following:

- the FBIS commands the Actuation System to perform its intended function through a dedicated signal;
- the Actuation System receives this request;
- the Actuation System performs its intended functions;
- the Actuation Systems updates its status information to reflect the actual status of its intended function.

The FBIS escalates to a Regular Beam Interlock, respectively Emergency Beam Interlock if it receives the acknowledgement later than a specified timeout.

The FBIS escalates to a Regular Beam Interlock, respectively Emergency Beam Interlock if the status feedback by the Actuation System does not match the expectation of the FBIS.

The FBIS implements the necessary custom interfaces to connect to the Actuation Systems. Note that some Actuation System may not feature an “acknowledge signal”.

6 Logging

The FBIS logs all input and output changes as well as all relevant internal information together with a timestamp for diagnostic purposes. These data will be available via the Higher-Level Control System interface for analysis.

7 Maintenance

The FBIS does in general not support maintenance while being in operation. Certain maintenance activities may be supported during operation (e.g. replacement of redundant power supplies) other activities will require stopping beam operation (e.g. reprogramming the FBIS decision logic).

8 FBIS Power-On Behavior

Upon Power-On, the FBIS carries out a Regular Beam Interlock.

The FBIS then performs necessary Power-On Self Tests to check its own health. In case the FBIS detects internal problems, the Regular Beam Interlock is kept and the system needs to undergo maintenance.

If the Power-On Self Tests pass successfully, the FBIS collects all information that are needed to perform the MP-SoS Configuration Consistency Check.

The FBIS clears all previously set masks and starts to perform its intended functions.

Only then the FBIS allows to reset the Regular Beam Interlock.

Appendix I

9 List of Assumptions

We assume that:

- custom components will be needed to manage reaction times of the order of µs (page 7)
- the FBIS directly interfaces with the Actuation Systems for Machine Protection purposes (page 7)
- PLC based systems do not directly interface with the Actuation Systems (page 8)
- the FBIS receives the necessary information from the ESS Timing System to differentiate between phases when beam is expected and when no beam is expected (page 8)
- the FBIS receives dependable information from MP-Related Beam Monitoring Systems whether proton beam is present directly downstream of intermediate beam destinations as defined by the proton beam destination (page 8)
- the FBIS receives dependable information from MP-Related Systems whether beam is present directly at the exit of the Ion Source (page 8)
- the FBIS receives dependable information from MP-Related Systems whether the Ion Source is successfully interlocked or not; Interlocking the source is equivalent to switching off plasma generation (page 8)
- the FBIS receives dependable status information from the LEBT and MEBT choppers to determine whether the beam is deflected or not (page 8)
- the FBIS can determine the Requested Proton Beam Destination from information provided by the ESS Timing System (page 12)
- all relevant MP-related Systems communicate the Proton Beam Destination they are configured for to the FBIS (page 12)
- the FBIS can determine the Requested Proton Beam Mode from information provided by the ESS Timing System (page 12)
- all relevant MP-related Beam Monitoring Systems communicate the Enforced Proton Beam Mode they are configured for to the FBIS (page 12)
- the FBIS has access to dependable information about the actual position of all interceptive devices(page 13)
- the FBIS has access to the intended position of each interceptive device, as set in the control system (page 13)
- the FBIS receives information from MP-related Beam Monitoring Systems in such a way that it implement this logic (page 13)
- all MP-related Systems that are using Proton Beam Destination information to perform their MP-related functions communicate the Proton Beam Destination they are configured for and are enforcing to the FBIS (page 15)
- all MP-related Systems that are using Proton Beam Mode Information to perform their MP-related functions, communicate the Proton Beam Mode they are configured for and are enforcing to the FBIS (page 15)
- the relevant systems will communicate health status information as well as a dynamic heartbeat signal, proving their correct functioning, to the FBIS (page 15)
- all relevant MP-related Systems will provide health information within acceptable time and with adequate information content (page 15)