The Beam Inhibit System For TTF II

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Abstract

The new generation of light sources based on SASE Free-Electron-Lasers driven by LINACs operate with electron beams with high beam currents and duty cycles. This is especially true for the superconducting machines like TTF 2 and the X-RAY FEL, under construction or planning at DESY. Elaborate fast protections systems are required not only to protect the machine from electron beams hitting and destroying the vacuum chamber, but also to prevent the machine from running at high loss levels, dangerous for components like the FEL undulator.

This paper will give an overview over the different protection systems under construction for TTF 2. The very fast systems, based on transmission measurements and distributed loss detection monitors, will be described in detail. This description will include the fast electronics to collect and to transmit the different interlock signals.

INTRODUCTION

The TESLA Test Facility phase 2 (**TTF 2**) is currently under construction at DESY in Hamburg. This machine has two main objectives [1]:

a) serve as a test facility for accelerator components for the future TESLA and X-RAY FEL [2],
b) operate as a 4^{th} Generation Light Source to provide SASE FEL radiation in the range between 100 and 6 nm.

In order to demonstrate the requirements for the large machines for high luminosity in case of the collider and high peak and average brightness in case of the SASE light source, the TTF 2 is capable to run a 800 µs long beam pulse at 10 Hz rep. rate with a 9 MHz bunch frequency. With the design charge of 1 nC this yields currents of 9 mA averaged over the bunch train, or a total average current of 72 µA.

Although the average current of TTF II is rather small compared to a typical conventional 3^{rd} generation light source, the intrinsic energy of this system is much higher (Table 1).

Table 1: Comparison of power and energy stored in the beam and losses for LINAC and storage ring driven light sources.

	Storage Ring	TTF 2
Average Current	200 mA	72 µA
Circumference/Length	200 m	250 m
Beam Lifetime	10 h	-
Energy	2 GeV	1 GeV
Avg. Beam Power	400 MW	72 kW
Energy (Beam/Pulsetrain)	0.26 kJ	7.2 kJ
Loss Level	10^{-7} (Undulator only)	$2\ 10^{-11}$ (total, 1/Turn)

Therefore, effective protection systems are required to prevent the machine from serious damage due to the operation. These systems have to protect the machine from different damage mechanisms resulting in different damage levels at different time scales, e.g.:

- Beam hitting a part of the vacuum chamber. The beam has to be stopped as fast as possible. In the worst case less then 10 bunches can cause damage. Therefore, the reaction time of the system has to be as short as possible, and is mainly determined by signal transmission times.
- Beam halo or dark current is (partially) lost in the machine. Such losses would result in increased activation of components. In the undulator accumulated losses can degrade the performance of the magnets substantially. Therefore, losses have to be observed down to a level of 10^{-7}.
- Invasive beam diagnostics or even obstacles are present in the beam pipe. Such an event has to be recognized by a protection system, to restrict the number of bunches within a bunch train to a number given by the sensitivity of the inserted object.

In order to allow safe machine operation, TTF 2 will have monitoring as well as interlock systems. There will be rather slow monitoring system based on Dosimetrie, using conventional Thermo-Luminescence-Dosimeters crystals and optical fibres. The fibre-based system can provide information about high dose rates in the machine with good spatial resolution and update rates of some minutes [3].

The active part of the protection system is taken by the Beam Inhibit System (**BIS**). This system was redesigned based on the experience with a predecessor system at TTF 1.

THE BEAM INHIBIT SYSTEM

In order to deal with different machine settings a number of operation and beam modes are defined.

Operation modes define the path the electrons have to take, like gun mode (beam stopped by a Faraday cup before the first module), undulator and bypass mode.

The beam modes determine, whether short, long or even only single bunch operation is allowed. These modes depend on the machine setting, e.g. if a screen is inserted only single bunch mode is allowed. Furthermore, they depend on the performance of the machine, i.e. the beam mode is switched back from long to short pulse or even to single bunch in the case the losses get too high or transmission gets too bad.

These actions are taken by the BIS system automatically depending on the settings of the machine.

The BIS is a PLC based system to collect all interlock relevant information and to use this information to block risky or dangerous operation modes. The interlock signals taken by the BIS are divided into two categories. Slow signals like screens, power supplies or valves are connected directly to the BIS. The reaction time to this information is 100 ms determined by the maximum pulse rep. Rate of the machine.

Fast signals, i.e. signals that require switching off the beam immediately within a bunch train, are collected by the **Fast Beam Inhibit System**. Signals connected to this system are the transmission based interlock system as well as the beam loss monitors. Furthermore, the fast acting valves and some fast RF signals are connected.

THE FAST BEAM INHIBIT SYSTEM

The fast beam inhibit system is a kind of distributed logical **OR**. It is built from beam concentrator units (**BIC**) with well-specified I/O channels, concentrating 16 input channels to 1 interlock output. The units can be cascaded and will be used to set up a tree like topology to collect the interlock signals (Fig.1) to one signal acting on the drive laser of the photoinjector. The reaction time is of the system about 2-3 µs, depending on type and location of the interlock source. It is dominated by the signal delay in the cables and the time of flight of the electron bunches from the gun to the detector.

In order to deal with different modes and also special situations during the operation, the parameters of the fast system are controlled by the BIS. It is possible to mask individual interlock channels by software for special machine operations. The interlock status of the system is provided to the control system on a shot to shot basis.

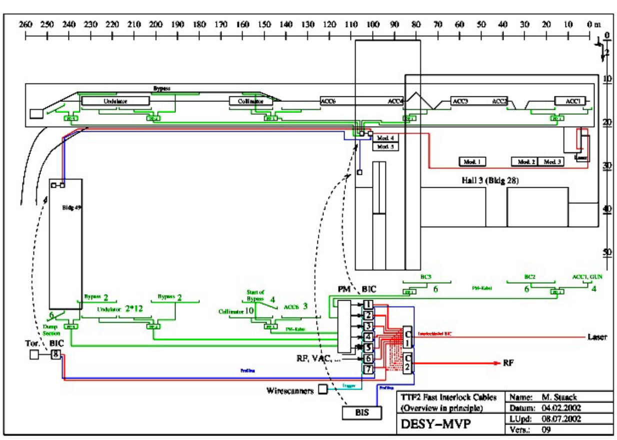

Figure 1: Topology of the BIC System.

The Beam Interlock Concentrator

The BIC modules (Fig. 2) are the central hardware to concentrate all fast interlock signals. 16 input channels are reduced to 1 output using a logical OR comparison with a processing time of 100 ns. In addition to the fast interlock output, there is a second output line to the BIS. As this system is a central safety system apart from speed redundancy is an essential requirement. Therefore, the hardware operates with 2 independent circuits, one based on discrete logics, the other on digital signal processing implemented in a FPGA. In addition to the basic processing, the FPGA provides additional features like a Profibus interface to the BIS with the possibility to

- Read back the status of the interlock inputs
- To two kinds of masks via the BIS; "hard-masks" in order to disable interlock channels permanently (for more than one bunch train) and "soft-masks" to disable them for a single bunch train only.

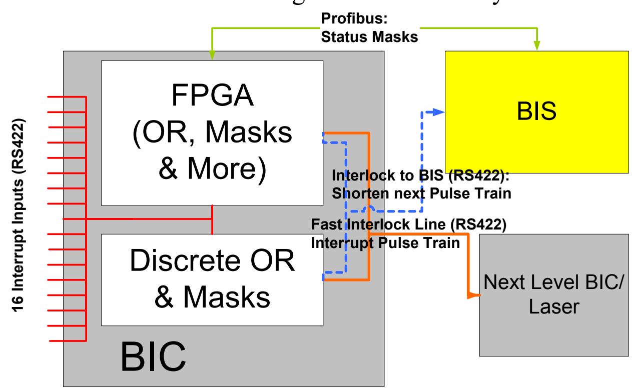

Fig. 2: Block Diagram of a BIC module and its interfaces.

In order to avoid problems due to ground loops all input channels have galvanic isolation. A differential communication line (RS422) is used for both input and output, with the levels chosen in a way that power failures and cable breaks will block the beam.

The Transmission Based Interlock System

In order to run the machine with high charge and high duty cycle, the transmission from gun to dump has to be close to 100%. The transmission is measured as a charge difference using pairs of charge monitors (toroids), as listed in table 2. Each toroid provides a signal with a bandwidth of about 100 MHz (single bunch resolution) with an accuracy of about 1%. Two pairs have been defined for the two operation modes: undulator and bypass operation. As the path length of an upstream and a downstream toroid can be up to 250 m, the minimum reaction time of this system cannot be faster than about 1µs. Including the signal processing and transfer time of the fast interlock system to switch off the laser this will add up to about 3 µs.

The toroid signals are transmitted to the protection system, located in a building at about ½ of the length of the machine. The electronics consists of fast ADCs and a digital signal processor per pair, to calculate the charge difference (Q_d - Q_u) between downstream and upstream monitor and to compare it on different time scales and with different alarm thresholds (T_{Qi}):

- Charge Validation:

  If $Q_u < T_Q$; $T_Q \approx 0.05$ nC; Input charge at upstream toroid not valid
- Single Bunch Transmission Threshold:

$$\left(\frac{|Q_u - Q_d|}{Q_u}\right)_i > T_{sgl}\,;\ \mathrm{T}_{sgl} \cong 25\ \%$$

The single bunch mode detects single bunch losses, if the threshold T_{Sgl} is exceeded an interlock is released.

- Slice Averaged Transmission Threshold:

$$\sum_{j=i-l}^{i}\left|\frac{Q_u - Q_d}{Q_u}\right|_j > T_{Slice}\,;\ \mathrm{T}_{Slice} \cong O(1\%)$$

In this mode the transmission in the bunch train is measured over a slice of bunches (i=O(100)) “moving” over the train. As soon as the averaged loss reaches the threshold T_{Slice} an interlock is released. Due to the averaging the resolution of the system will improve compared to the single bunch resolution. Slice resolutions down to 10^{-3} are expected.

- Pulse Integrated Transmission Threshold:

$$\sum_{i=0}^{n}|Q_u - Q_d|_i > T_{\mathrm{int}}\,;\ \mathrm{T}_{int} \cong O(10\ nC)$$

The integration mode sums the losses over the whole bunch train. An interlock is released as soon as the threshold is reached. A threshold of 10 nC corresponds to 1 10^{-4} of the nominal charge within a bunch train.

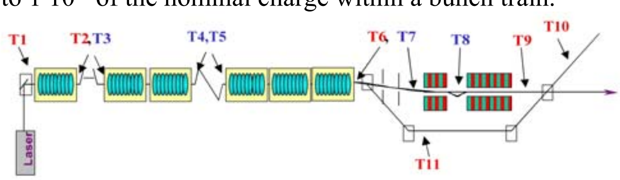

Figure 3: Sketch of TTF 1, showing of charge monitors along the machine. Devices indicated in red serve as input for the protection system.

Table 2: Toroid Pairs for the Protection System

Toriod 1	Toriod 2	Purpose
T_1	T_9	Undulator Mode
T_1	T_{11}	Bypass Mode
T_2	T_{10}	Transmission to the dump (undulator beam path)
T_2	T_{10}	Transmission to the dump (bypass beam path)

The Beam Loss Monitor System

The beam loss monitor (BLM) system is based on measurements of radiation due to the electromagnetic showers produced by lost electrons. The monitors are located at positions that are rather radiation sensitive. Compared to the global acting transmission based protection system, it has much higher, but localized sensitivity O(10^{-7})) [4]. Thus both systems complement each other, providing high redundancy and safety for the machine.

Beam losses will be measured by 49 photomultipliers (PMs) equipped with scintillator and 18 secondary emission multipliers (SEMs) equipped with Al cathode. The multipliers will deliver a 20 ns long pulse with an amplitude of up to 100 mA. As the reaction of the PM system depends only on the input of a single sensor, the reaction time of the system is dominated by the cable length from the detector to the laser. Thus is can be significantly faster than the toroids (< 2µs). Fig. 3 gives a schematic view of the BLM distribution along the accelerator. Scintillator plates (40 x 40 cm and 10 x 10 cm) are foreseen to be installed along the linac, long scintillator rods (220 x 5 cm) will be placed parallel to the undulator vacuum chamber. SEMs will be placed in locations like collimator and dump sections, where rather high radiation levels have to be expected.

The readout of the BLMs will be done by a special VME based electronics. These VME-systems will also control and monitor the high voltage (HV) of the multiplier units and are able to generate test pulses. Each loss monitor will release alarms for immediate beam pulse interruption to the BIC in case of exceeding thresholds due to high losses from the beam or dark current (distinguishing between these two loss sources) or if the HV is missing.

For recording of the data the losses are integrated over a time period of 9 bunches and the time of the following bunch is used to digitise and reset the integrator. The loss profile of course is the main tool to optimise the performance of the machine.

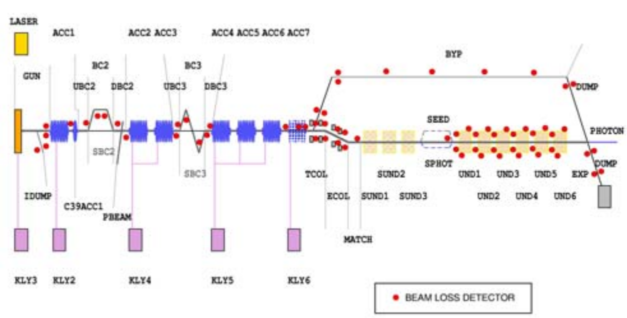

Figure 4: Sketch of TTF 2; the red dots indicate the position of the BLMs along the machine.

References

[1] TESLA-FEL Report 2002-01, DESY 2002
[2] TESLA; Technical Design Report & XFEL Supplement, DESY 2002/2003
[3] M. Koerfer et al., Optical Fibre Dosimeter for SASE FEL Undulators, this procedings
[4] H. Schlarb et al., Expansion of the Fast Linac Protection System for High Duty Cycle Operation at the TESLA, EPAC 2002, Paris