

FIBRE MONITORING SYSTEM FOR THE BEAM PERMIT LOOPS AT THE LHC AND FUTURE EVOLUTION OF THE BEAM INTERLOCK SYSTEM

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Abstract

The optical fibres that transmit the beam permit loop signals at the CERN accelerator complex are deployed along radiation areas. This may result in increased attenuation of the fibres, which reduces the power margin of the links. In addition, other events may cause the links not functioning properly and result in false dumps, reducing the availability of the accelerator chain and affecting physics data taking. In order to evaluate the state of the fibres, an out-of-band fibre monitoring system is proposed, working in parallel to the actual beam permit loops. The future beam interlock system to be deployed during LHC long shutdown 2 will implement online, real-time monitoring of the fibres, a feature the current system lacks. Commercial off-the-shelf components to implement the optical transceivers are proposed whenever possible instead of ad-hoc designs.

INTRODUCTION

The Beam Interlock System (BIS) [1] of the CERN accelerator chain is responsible for transmitting the beam permit along the Large Hadron Collider (LHC), the Super Proton Synchrotron (SPS), the transfer lines and the PS Booster.

The beam permit loop signals are two different square wave signals with frequencies 9.375 (loop A) and 8.375 MHz (loop B), sent in opposite directions. These beam permit signals are transmitted over single-mode optic fibre.

Figure 1 shows the topology of the beam permit loops at the LHC. There are two signals for each of the two beams, one transmitted clockwise and the other anti-clockwise.

There are seventeen Beam Interlock Controllers (BIC) in the LHC, two at each LHC point, named with the point number and side (left or right), and one at the CERN Control Centre (CCC), named CCR. The two generators of the beam permit signal, named CIBG, are installed in point 6, where the dump system is located.

In the SPS, there is a similar architecture, with one BIC per point, and two loops for one beam. Injection and extraction lines also have their own beam permit loops.

The controllers receive the users inputs, coming from the user systems. These inputs are connected with a logical AND inside the controller, resulting in the local permit at the BIC. If the local permit is true, then the BIC re-transmits the beam permit signal to the next BIC.

A total of 12 fibres are deployed at each controller: one for each incoming signal and one for each outgoing signal, for a total of eight active fibres. There are two spare fibres to each of the neighbour controllers. The distance between

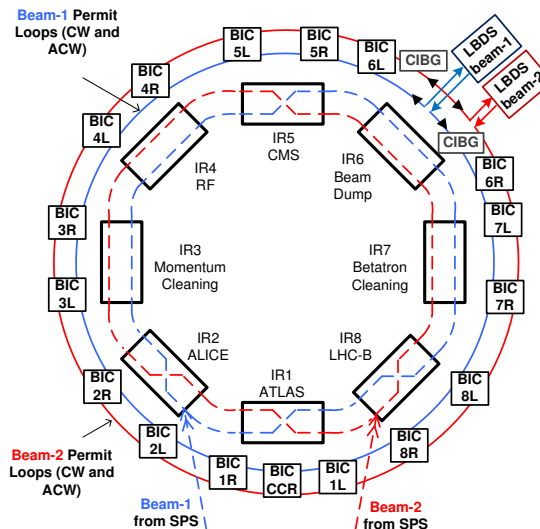


Figure 1: LHC beam permit loops.

controllers is varied, as short as a metre and as long as 6 kilometres.

OUT-OF-BAND FIBRE MONITORING

Motivation

The beam permit loops and the implementation of the optical links are described in [2]. The Controls Interlocks Beam Optical (CIBO) board designed at CERN uses an ELED single-mode transmitter and a PIN diode receiver to implement the optical transceiver for the beam permit signals.

The working wavelength of the loops is 1310 nm, and the receiver has a sensitive response in the range (900, 1700) nm. The output power of the transmitter is typically between -25 and -15 dBm and the CIBO board is designed to deliver around -19 dBm.

The G.652 [3] type optical fibres have a maximum length of 6 km, with an initial worst case attenuation of 0.5 dB/km at 1310 nm. A number of false dumps have occurred that may have been caused by increased attenuation in the fibres, what drives the need for a monitoring system to evaluate their performance during operation.

Radiation can both create point defects in the silica and activate already existing defects, causing radiation induced

attenuation (RIA) [4]. Therefore, a system to monitor the fibres attenuation is advisable.

Such a monitoring system for the LHC and SPS fibres must not interfere with the Beam Permit Loop signals, as they are critical to the accelerator operation. It would be convenient to have measurements of the fibres attenuation over time, and the capability to monitor both spare and active fibres.

The existing beam permit loop signals cannot be measured directly due to the tight power margins involved. The use of a tap with sufficient coupling ratio that allows for the measurement of the optical power is discouraged because of the high extra losses on the links.

As an alternative, the transmission of a separate optical signal over the existing fibres is proposed. The use of Wavelength Division Multiplexing enables the transmission of multiple signals over the same fibre.

A Wavelength Division Multiplexer (WDM) is a passive and bi-directional device, which has one common port, in which multiple wavelengths can be transmitted at the same time, and two (or more) ports which only allow one wavelength.

Monitoring System

A large wavelength separation of the monitoring signal with respect to the beam permit loop signals was evaluated. The chosen wavelength is 1550 nm, which is in a separate window from the beam permit loop transmitter. Nevertheless, the receiver is sensitive to this window, an effect that has to be evaluated in order to verify that the beam permit loops are not disturbed by the monitoring signal.

Standard commercial components for the system were chosen in order to ease development and deployment. The transceivers are Standard Small Form-factor Pluggable (SFP) [5]. These typically implement a diagnostics information interface [6] which allows for the measurement of transmitted and received power.

Commercial network switches are used to house, power and access the monitoring information on the SFPs. A computer is used to connect to the switches, retrieve the information and process it.

In order to be able to separate the optical signals, commercial WDMs have been evaluated and a system has been proposed and tested. The isolation provided by these devices is tight for 1550 nm systems, as these are high power devices, in the order of 0 dBm, two orders of magnitude higher than the beam permit loop signals. Nevertheless, disabling the ports on the switch eliminates the interference from the SFP transceiver to the beam permit loops receivers, while still permitting the power measurements.

The transmission of the beam permit loop signals through WDMs does not cause any significant signal degradation.

A proposed topology to monitor a link is shown in Fig. 2, where the two points of one beam permit loop link are shown. The monitoring signal is sent in the opposite direction from the beam permit, to take advantage of a higher isolation between the two input ports of the WDM.

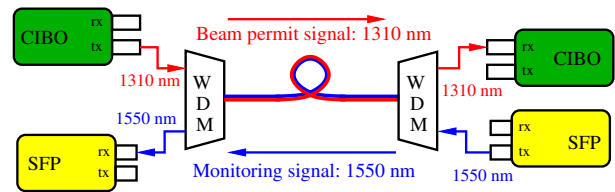


Figure 2: Monitoring system using WDMs and SFPs to transmit a monitoring signal in parallel to the beam permit signal.

Due to the large power margin of the SFP transceivers, attenuators are also used in this topology to reduce the power in addition to the WDM isolation.

A first test system was installed in the SPS spare fibres, between points BA4 and BA6. A BIC was installed and configured in BA5, together with two switches that held the SFP transceivers to monitor the attenuation. The BIC was set to latch mode and the whole system ran for 30 days, without observing any losses of the beam permit. Attenuators were connected at the transmitter outputs of the SFP transceivers, with an attenuation of 10 dB.

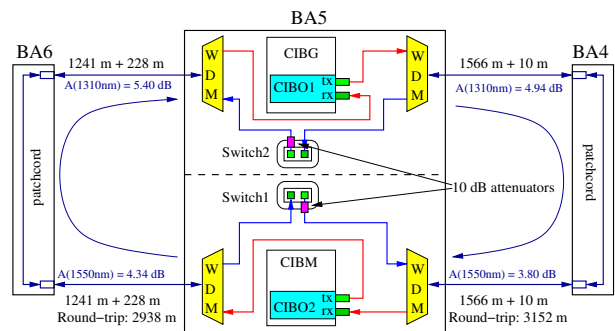


Figure 3: Test setup in the SPS with two switches, WDMs and a Beam Permit Loop emulating two locations using three SPS sites.

A drawing of the test setup is shown in Fig. 3. The topology effectively emulates two separate locations, with one CIBO transceiver at each one, and the monitoring system connected to two fibres.

LHC Fibre Monitoring

The system is deployed at the LHC, measuring a selection of spare fibres around the ring. In order to avoid any interference with the system due to the connection of the WDMs, no live fibres are monitored. Since the measured fibres are spares and there is no beam permit signal on those, no WDMs are required. The information from this setup is nonetheless useful to track whether the fibres are being affected by radiation while the LHC is in operation.

In order to limit the number of switches, three locations were selected to install the switches: points 1, 3 and 7. Loop-back connections are in place so the fibres are measured from each switch alone. Bypass connections are used at the

shortest paths at the same LHC point to go to the next LHC point.

The monitored fibres are (all returning to the first point):

- US15 to UA23 (point 1-point 2).
- US15 to CCR (point 1-CCR).
- US15 to UA87 (point 1-point 8).
- SR3 to UA43 (point 3-point 4).
- SR3 to UA27, with a bypass at UJ33 (point 3-point 2).
- SR7 to UA67 (point 7 to point 6).
- SR7 to UA83, with a bypass at TZ76 (point 7-point 8).

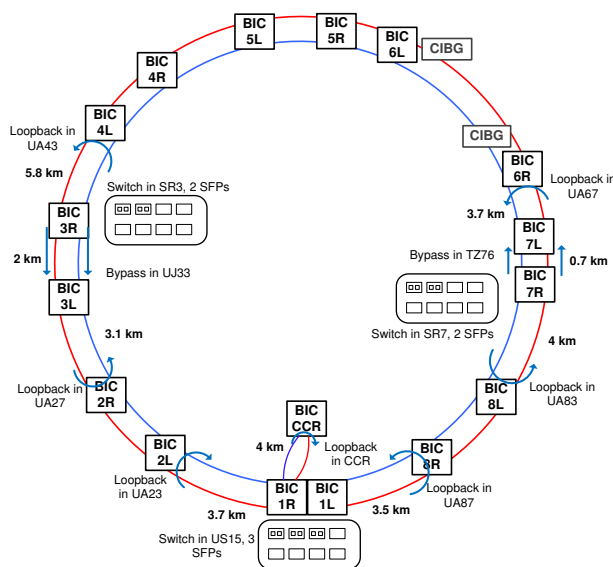


Figure 4: Fibre monitoring system on LHC spare fibres. Bypasses and loopback connections are shown, as well as the location of the switches holding the SFPs.

The topology of the deployed monitoring system is shown in Fig. 4. The choice of the fibres to be monitored was made so they are close to high radiation areas, such as the collimators in points 3 and 7.

UPGRADE OF THE BEAM INTERLOCK SYSTEM

An upgrade of the beam interlock system should be ready, at the earliest, for the long shutdown 2, starting in 2018.

Some of the components used in the design of the current BIS are close to becoming deprecated by the manufacturers. In order to ensure the availability of the beam interlock system in the future, selection of the components is now under study. In order to take advantage of their reliability, interoperability and the ease of insertion and extraction, SFP transceivers are being used for the research and development phase of the next version of the beam interlock system.

The monitoring and diagnostics capabilities of these devices, combined with the availability of manufacturers makes it an appropriate choice. In addition, the variety of configurations that they allow is ample enough to cover many scenarios at the CERN accelerator complex. SFP transceivers from most manufacturers have versions with different output power values, leading to several power margins that can be used to accommodate the various fibre lengths of each link, or even to compensate for increased fibre attenuation.

The BIS upgrade must be compatible with the current systems, meaning the interfaces and signals have to be compatible with the original system. Due to the compatibility requirement, the new programmable devices have to be carefully chosen in order to be capable of implementing all input and output signals that exist in the current BIS.

The implementation of the Beam Permit Loops will also be studied, checking the possibility of transmitting data messages instead of a fixed loop frequency.

CONCLUSION

Fibre attenuation increase due to radiation is a concern for the BIS, as it affects its reliability and availability of the LHC. The current system lacks monitoring capability and the addition of a measurement system is troublesome. The use of commercially available, standardised SFP transceivers enables the measurement of the optic fibre attenuation, either active fibres through wavelength division multiplexing or spare fibres.

A monitoring system has been installed in the LHC spare fibres to measure the time evolution of fibre attenuation in high radiation areas.

SFP transceivers are also being evaluated for the next version of the beam interlock system, to transmit the beam permit loop signals at the CERN accelerator complex. The flexibility and features provided by these transceivers are of great interest to the next version of the BIS.

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