FIRST EXPERIENCES OF BEAM PRESENCE DETECTION BASED ON DEDICATED BEAM POSITION MONITORS

A. Jalal, S. Gabourin, M. Gasior, B. Todd, CERN, Geneva, Switzerland

Abstract

High intensity particle beam injection into the LHC is only permitted when a low intensity pilot beam is already circulating in the LHC. This requirement addresses some of the risks associated with high intensity injection, and is enforced by a so-called Beam Presence Flag (BPF) system which is part of the interlock chain between the LHC and its injector complex. For the 2010 LHC run, the detection of the presence of this pilot beam was implemented using the LHC Fast Beam Current Transformer (FBCT) system. However, the primary function of the FBCTs, that is reliable measurement of beam currents, did not allow the BPF system to satisfy all quality requirements of the LHC Machine Protection System (MPS).

Safety requirements associated with high intensity injections triggered the development of a dedicated system, based on Beam Position Monitors (BPM). This system was meant to work first in parallel with the FBCT BPF system and eventually replace it. At the end of 2010 and in 2011, this new BPF implementation based on BPMs was designed, built, tested and deployed.

This paper reviews both the FBCT and BPM implementation of the BPF system, outlining the changes during the transition period. The paper briefly describes the testing methods, focuses on the results obtained from the tests performed during the end of 2010 LHC run and shows the changes made for the BPM BPF system deployment in LHC in 2011.

INTRODUCTION

A high intensity particle beam injection into the LHC must not be permitted if no low intensity beam is already circulating, confirming the set-up of the primary machine parameters, like beam orbit, operational point, chromaticity, etc. For this reason, the extraction and injection process of beam from the SPS to the LHC is tightly interlocked. Two BPF flags, one for each beam, are generated and transmitted to the extraction interlock systems indicating the presence, or absence, of a circulating beam in the LHC.

In the 2008, 2009 and 2010 runs each flag was derived from the system measuring the beam currents passing through the FBCTs installed on the LHC beam pipes. The FBCT system was designed for beam instrumentation purposes and could not fulfil all rigorous requirements of the LHC MPS. To increase the reliability of this important protection feature a dedicated BPM system has been developed in addition to the FBCT solution. Finally, in the spring of 2011 the FBCT BPF system was phased out in favour of the dedicated BPM implementation.

SYSTEM ELEMENTS

The BPF system uses signals from the FBCT and BPM systems. The BPM BPF system [1] is based on four signals per LHC beam derived from electrodes of a dedicated BPM. Each electrode drives an input of a dedicated BPF analogue front-end [1], which in turn derives Boolean beam presence flags. For beam-1 these flags are BPF_1A, 1B, 1C and 1D, for beam-2: BPF_2A, 2B, 2C and 2D. The BPF front-end sets a flag to TRUE if the corresponding signal exceeds a threshold and the beam has been already circulating for certain time.

A pair of FBCTs also evaluates beam presence based on the circulating beam characteristics, deriving BPF_1E and 1F for beam-1, 2E and 2F for beam-2. This gives a total of six flags per beam as illustrated in Fig. 1.

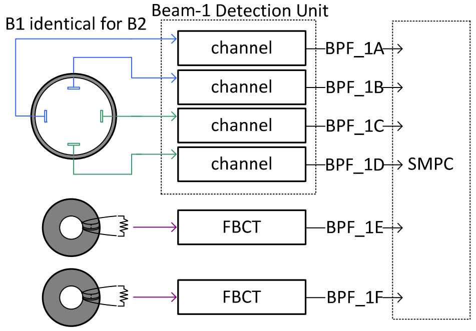

Figure 1: System Elements.

These flags are then transmitted to the Safe Machine Parameters Controller (SMPC). The SMPC logic carries out a voting on the six input flags using a pair of two-out-of-three (2 oo 3) majority voter blocks and also filters the signals to remove spurious transitions. This results in a pair of Beam Presence Flags per beam which are transmitted to the extraction Beam Interlock System (BIS). This pair is also combined to give a single BPF which is broadcast for general consumption via the LHC General Machine Timing (GMT), as sketched in Fig. 2.

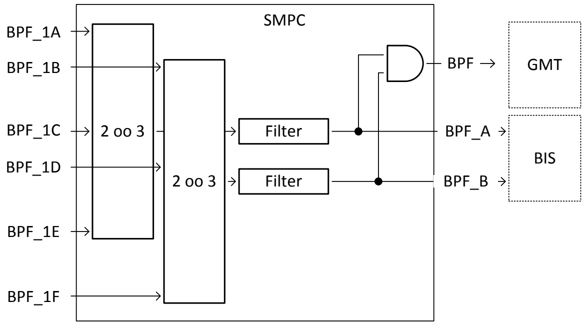

Figure 2: Combination and Voting Logic.

TESTING AND CHARACTERISATION

The BPM implementation was tested in parallel with LHC operations in late 2010. This allowed the system to be characterised with respect to the FBCT.

The test consisted of comparing two of the BPF from the BPM (BPF_1A and BPF_1B) with intensity values during ordinary LHC operations with beam. The intensity values were given by the LHC FBCT, the BPF values were logged by the BIS. The test period covered five weeks of 2010 operation with beam (25/10 – 19/11).

As the LHC was operating normally with beam, there were a large amount of transitions. For the analysis, the key area of interest was the intensity value at the moment of a BPF transition from TRUE to FALSE, or from FALSE to TRUE. Figure 3 shows typical characteristics of intensity, threshold and BPF transitions.

Threshold During Normal Operation

The beam intensity was recorded at the time of every flag transition; this resulted in a consistent value of intensity with an average around 3 x 109, as shown in Table 1. There are, however, two important limitations in this test method: The Pick-up selection, and the FBCT accuracy.

The pick-ups being used for the characterisation were those on the upper and left side of the beam pipe as shown in blue in Figure 1. The signal amplitude on each BPM electrode depends on the distance of the beam to the electrode, so the signals are only equal for a centred beam. The minimum intensity threshold values observed are related to a beam that was circulating closer to the BPM electrode, resulting in a larger signal. On the other hand, the maximum threshold intensity values are due to a beam circulating further from the BPM electrode, thus giving a smaller signal. These results are summarised in Table 1.

Table 1: Thresholds for the BPM BPF system

	Beam 1	**Beam 2**
Min value	2.11×10^9	1.75×10^9
Max value	6.05×10^9	6.33×10^9
Average	3.3×10^9	3.5×10^9

On average, the beam intensity at the transition point, with significant position dependence, is around 3×10^9 charges. The observed intensity threshold dependency on beam position was removed for the 2011 implementation [1].

The second limitation with this method is that it followed normal LHC operation, where the beam is injected or dumped in a single turn, with the threshold value given from the FBCT reading at that instant. The threshold value determined in this manner is dependent on the measurement algorithm and time delays of the FBCT system. Therefore a dedicated run was organised, to determine the threshold of the BPM system with a higher precision.

Threshold During Dedicated Run

Slowly decreasing the beam intensity proved the best method for determining the threshold, as the threshold is passed, oscillations of the BPFs occur. Oscillations like this are the best indicators that the beam is very close to the threshold value of the dedicated BPMs. As shown in Table 2, the threshold was determined to be around 6×10^8 charges giving rise to a noise around 2 kHz.

Table 2: Low Intensity Noise

Flag	**Time**	**Intensity**	**Frequency**
Beam 1	04:15:43.956	5.9×10^8	2.1 kHz
Beam 2	20:19:12.617	5.9×10^8	2.4 kHz

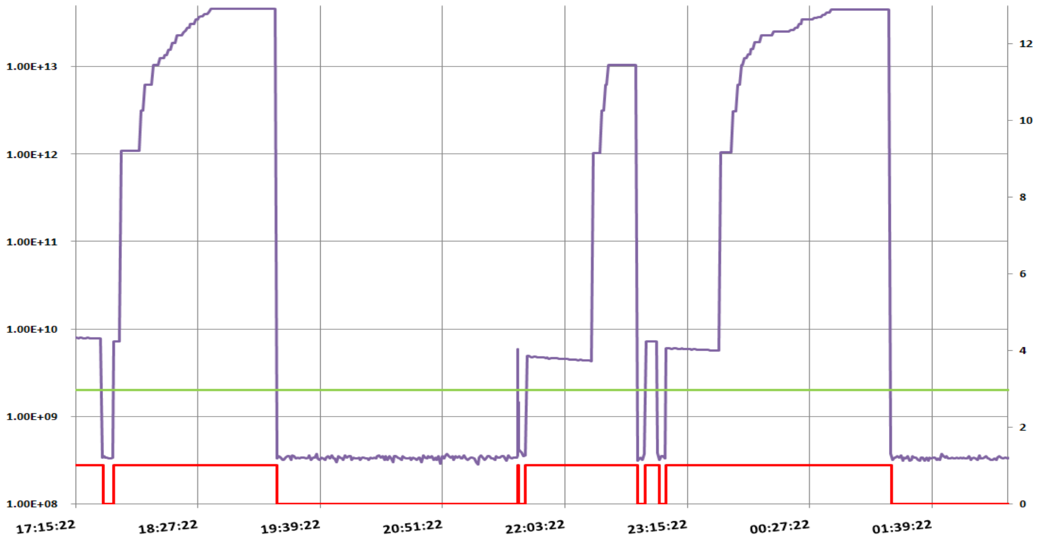

Figure 3: Intensity (Purple), Threshold (Green) and Beam Presence Flag (Red) Normal Operation.

This noisy behaviour was only observed in the case of *decreasing* intensity, and not in other situations. This is due to the noise being only observable when the intensity variation is relatively slow. An injection of beam into LHC represents an instantaneous (turn-by-turn) increase of the intensity, well above threshold, which doesn't give any noise on the BPF signals.

The noisy transitions for beam intensity close to the threshold were removed for the 2011 implementation [1].

Time Delay

As the individual BPF system channels are independent, a time delay could be observed between the BPF_1A and 1B signals. Table 3 shows an example of this situation. The first two rows have no time difference between flags: they both switch to true at the same time, corresponding to an injection of beam into the LHC. On the other hand, the second and third rows show that the two flags change the state to FALSE at well different times: BPF_1A is delayed by some three minutes compared to BPF_1B:

Table 3: Pick-Up Time Delay

Time	Transition	Flag
09:50:59.410	F→T	BPF_1A
09:50:59.410	F→T	BPF_1B
10:59:21.900	T→F	BPF_1B
11:02:42.541	T→F	BPF_1A
11:30:53.410	F→T	BPF_1A
11:30:53.410	F→T	BPF_1B

Of the 600 transitions analyzed, 93% of them have a delay between flags of less than 3µs. The remaining 7%, with the exception of the single example above, have a delay between 30ms and 90ms. In all cases this corresponded with a very slow gradual decrease in beam intensity, and on a flag transition from TRUE to FALSE. The discrepancy in switching times was attributed to off-centred beam.

2011 IMPLEMENTATION

The characterisation of the BPM implementation in 2010 was very successful, and a revised implementation of the BPF electronics was put into operation in summer 2011. This included four important changes to address observations from 2010 [1]:

Position Dependence

As shown in Fig, 4, signals from the opposite BPM electrodes are summed before being split and passed to the channels of the BPF front-end. This removes most of the dependency on beam position for the evaluation of the flags.

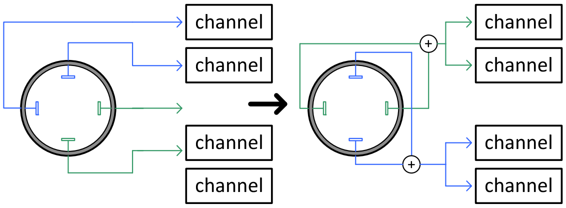

Figure 4: Suppression of Position Dependence.

Hysteresis

Hysteresis was added to remove noisy transitions as the beam intensity passes through the threshold.

Threshold

The threshold of 6×10^8 was considered to be a good demonstration of the system sensitivity, at the same time, was lower that the threshold intensity of the LHC beam orbit measurement system. This system is essential for reliable LHC operation, so beam intensity must guarantee its operation. For that reason the BPF system threshold was raised to about 2×10^9 charges, by attenuating the BPM signals before the BPF analogue front-end (see Fig. 5).

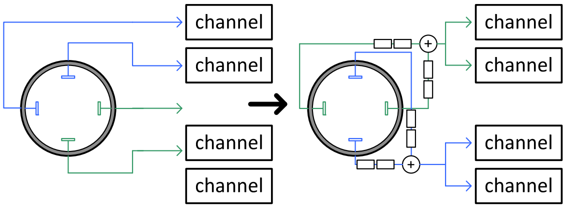

Figure 5: Increase of Threshold.

Fast Beam Current Transformer

Finally, the flags from the FBCT system were disabled from the voting logic of the SMPC. Instead of operating with six BPF and two 2 out of 3 voters, there are four BPF, which must all be TRUE for the corresponding global BPF to be TRUE.

CONCLUSIONS

The prototype beam presence flag system based on BPM signals was tested in principle in 2010 and with minor modifications was put into regular operation for the 2011 LHC run. Whilst the system has been proved to work with a threshold of 6×10^8, it has been implemented with a threshold of 2×10^9 to protect the LHC.

ACKNOWLEDGEMENTS

This work has been the result of a close and productive collaboration between the LHC machine protection and LHC beam instrumentation groups.

REFERENCES

[1] T. Bogey, M. Gasior, "The LHC Beam Presence Flag System", DIPAC 2011, CERN-BE-2011-026.