DESIGN ASPECTS RELATED TO THE RELIABILITY OF THE LHC BEAM DUMP KICKER SYSTEMS

J.H. Dieperink, J.-L. Bretin, E. Carlier, L. Ducimetière, G.H. Schröder,
E. Vossenberg, CERN, Geneva, Switzerland

Abstract

The two LHC beam dump kicker systems consist each of 14 pulse generator and magnet subsystems. Their task is to extract on request the beams in synchronisation with the gap in the beam. This operation must be fail-safe to avoid disastrous consequences due to loss of the beam inside the LHC. Only a failing operation of one of the 14 pulse generators is allowed. To preserve this tolerance premature beam dumps are forced immediately after early detection of internal faults. However, these faults should occur rarely in order not to be a source of undesirable downtime of the LHC. The report determines first the level of reliability required for the main components of the system. In particular faults which could cause spontaneously non-synchronised beam dumps are identified. Then, technical solutions are evaluated on failure behaviour. Those having a most likely failure mode which does not cause dump triggers are favoured. These solutions need redundancy and are more complex but have the advantage to be fault tolerant. The design goal can be achieved with a combination of high quality components, redundant signal paths, fault tolerant subsystems, continuous surveillance and check-list validation tests before the start of the injection of beam in the LHC.

1 INTRODUCTION

The LHC beam dump kicker system must be able to safely dump the beam at any stage during the filling, the accelerating and colliding phase, i.e. from the injection energy of 450 GeV up to the top energy of 7 TeV. The circulating beam, with a nominal maximum energy of 334 MJ per ring, must be extracted in one single turn of 89 µs duration [1].

Severe damage can be induced to the LHC, due to full or partial loss of the beam onto machine components. This can happen when no response is given to a request for dumping the beams or when the dump kicker system works incorrectly.

Possible faults can be classified in 3 types as follows:

1. Faults detectable early enough such that a dumping action without risk can be done, e.g. a faulty charging supply with consequence of a slowly decaying stored energy on the capacitor. These faults reduce the availability of the LHC for physics.
2. Faults occurring during the dumping action. These faults can cause damage when occurring coincidentally on more then one subsystem.
3. Faults generating a spontaneous dumping action unsynchronised with the particle free gap in the beam. These faults can result in a quench in the super conducting magnets. However, the overall system is conceived such that no damage occurs.

The required reliability and the preferred fault behaviour of the main components of the dump kicker system have been determined such that the risk for damage to the LHC is minimised and the availability for physics runs is maximised. The study has been restricted to the dump extraction kicker system and its service equipment. The generation of requests and their transmission has not been dealt with.

2 SHORT DESCRIPTION OF THE DUMP KICKER SYSTEM

Figure 1 shows a functional lay-out of the main components of the beam dump extraction kicker system.

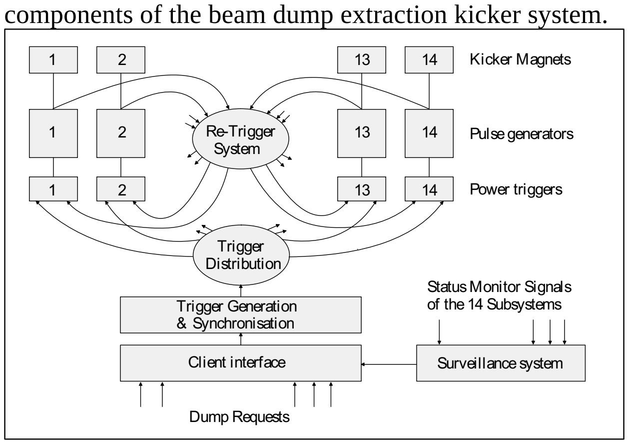

Figure 1. Functional lay-out of the dump kicker system.

The 14 dump *kicker magnets* are powered by 14 *pulse generators* which get the trigger from *power trigger* modules. The *trigger generation and synchronisation* system distributes the trigger requests, from the *client interface*, to the *power triggers* in synchronisation with the gap in the circulating beam. There is a *re-trigger* system, which has the task to detect any spontaneous trigger in one of the pulse generators and to re-distribute this information, as fast as possible, to all remaining pulse generators as trigger pulse. Finally, there is a *surveillance system* which has the task to issue a dump request when a severe fault has been detected.

0-7803-4376-X/98/$10.00 © 1998 IEEE

3 REQUIRED PERFORMANCE

The required performance for safe operation can be summarised as follows:

1. The failure rate of the execution of a request for a beam dump should not exceed 1 failure/10^6 hours.
2. Operation of 13-out-of-the-14 magnet systems is sufficient to dump the beam safely. However, when one out of the 14 systems becomes faulty, the beam must immediately be dumped. The rate of these faults must remain orders of magnitude lower than the rate of normal beam dump requests. The failure rate of the execution of this request should not exceed 1 failure/10^6 hours.
3. A spontaneously generated trigger in one of the systems must trigger immediately all other systems. Therefore the maximum admissible rate of these triggers has been set to less than 1 event/year. The failure rate of this re-triggering process should not exceed 1 failure/10^6 hours.
4. The reliability must be such that the availability of the LHC for physics is not reduced significantly.

4 THE RESULTING REQUIREMENTS

For the estimation of the reliability and the risk of all systems a same failure rate of less than 1 failure/year/subsystem has been assumed. In reality this will not be the case because the complexity of the different systems is rather different. However, it gives the possibility to rank the order of risk that the different systems provide. The following conclusions have been drawn:

- The failure behaviour of the *trigger generation*, the *trigger distribution*, the *re-trigger*, the *power trigger* and the *pulse generator* must be fault tolerant, i.e. a fault should not cause a current pulse in the magnets but should result in unavailability. Hence, redundant equipment must take over the task of an unavailable element.
- The failure behaviour of the *surveillance system* and the *fault detectors* in the whole system must be fault tolerant, i.e. the occurrence of an internal fault must initiate a safe action, which is in most cases a dump request.
- Redundant *power trigger/pulse generator* chains are necessary, otherwise the risk that less then 13 chains work simultaneously is above the required level.
- The more complicated *power trigger/pulse generator* chains have a higher failure rate than the relatively simple *trigger and trigger generation* systems. Every effort in the choice of material must be made to keep this failure rate below 1 failure/year/chain.
- A redundant *normal trigger* system is necessary to meet the requirements.
- A redundant *re-trigger system* is not really necessary but remains recommended.
- Redundant *trigger generation and synchronisation systems* are necessary. To ensure that the beam dump is requested when both systems fail simultaneously, a different third redundant system is needed.
- Non relevant but nevertheless necessary equipment should not have any impact on the availability of the dump kicker system.

5 APPLICATION TO THE HARDWARE

5.1 Prototype pulse generator

The prototype pulse generator, constructed and successfully tested in 1994, is actually composed of two parallel circuits (called A and B) connected to a common power switch. The subdivision is required for reduction of the leakage inductance and the generation of an acceptable pulse shape. Two types of power switches have been tested. A gas switch [2] and recently a solid state switch [3].

5.2 Proposed final generator

To achieve the requirements enumerated in chapter 4 the following choices and additions are proposed:

- The generators will be equipped with solid state switches because the spontaneous discharges in gaseous switches are more likely and lead to faults of type 3 (chapter 1).
- Instead of connecting both subsystems to one power switch, each unit will be equipped with its own switch. Both switches are interconnected such that each takes normally half the current, but is capable to conduct the full current in case of unavailability of its partner.
- Two other interconnections between the two units provide additional fault tolerant behaviour in case of unavailability of other important generator elements.

Figure 2 shows a block diagram of the pulse generator with its power trigger units.

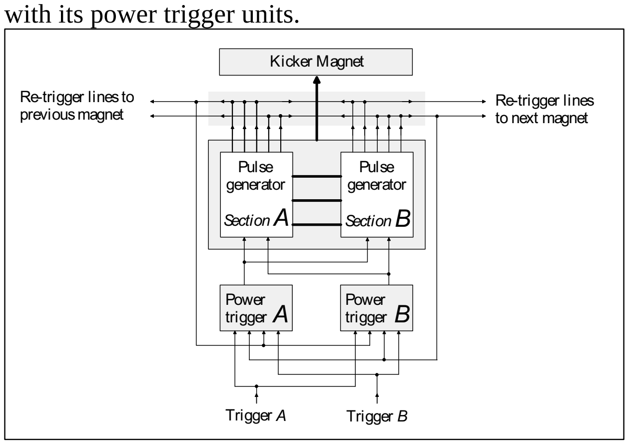

Figure 2. Block diagram of the power trigger/pulse generator/magnet chain.

5.3 Normal trigger and re-trigger system

Figure 3 shows the principle of the re-trigger system whose task is to re-transmit a trigger from one generator as fast as possible to all others.

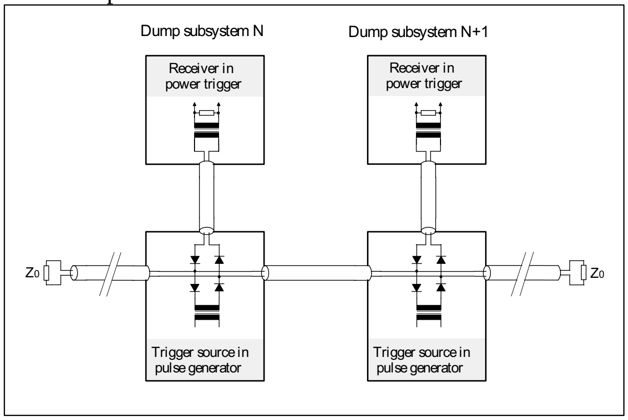

Figure 3. Principle of the re-trigger system.

A chained input/output system has been chosen instead of a star system because it is faster. Each pulse generator has several re-trigger sources originating in the other 13 pulse generators. One trigger source has enough energy to trigger all power trigger modules. Since there is no stored energy in the system itself it is difficult to create spurious triggers, neither can a disconnected cable nor a defective trigger source cause triggers.

The normal trigger distribution system has no constraints on speed and can use the same technology.

5.4 Trigger generation and synchronisation system

Figure 4 shows the principle of the proposed trigger generation and synchronisation system.

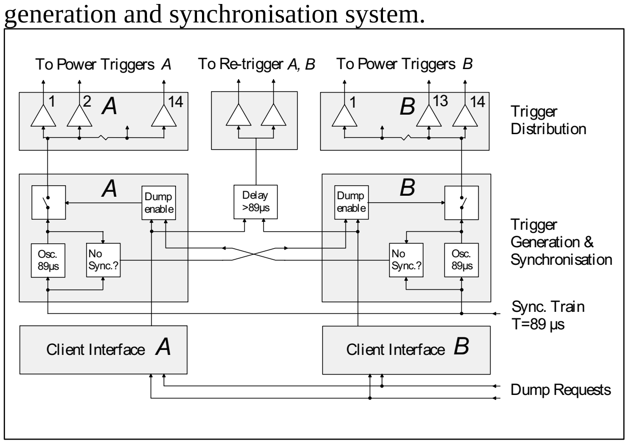

Figure 4: Client interface, trigger generation, synchronisation and distribution

Quartz controlled generators produce continuously dump trigger pulses synchronised with the gap in the circulating beam. Internal distribution of these pulse trains is inhibited until a beam dump is requested. The pulses which pass the inhibit stage are sent via a fan-out system to all power trigger modules. In this way the first pulse after the reception of a dump request will trigger the system. If synchronisation is lost, a synchronised beam dump remains nevertheless possible for several seconds, because of the stability of the quartz oscillator. If the synchronisation of only one of the oscillators fails, a dump trigger is forced by the redundant system. This mechanism reduces the probability of non synchronised dumps to almost zero. Any dump request sends also a dump trigger, delayed by 89 µs, via the re-trigger system to the power trigger modules. This third trigger path guarantees that a beam dump is initiated, even when both principle systems fail.

5.5 Surveillance system

The surveillance system continuously collects status information and makes a beam dump request when a fault appears. It collects also the post mortem information generated by a dump or by a test program which is used to validate the safe operation of the system. Special attention must be paid to the large volume of information needed for these tests. Commercially available PLCs are foreseen to be used for this purpose.

6 CONCLUSION

The reliability study of the extraction kicker systems of the LHC beam dump confirms that most attention must be paid to the high voltage pulse generators and their power switches to assure fault tolerance and availability. It is therefore proposed to employ solid state power switches rather then gaseous switches whose risk of spontaneous breakdown, which would entail spontaneous unsynchronised dumps, is most likely greater. These solid state switches will be doubled to assure fault tolerance and availability.

The stringent reliability requirements impose also the duplication of the auxiliary systems for triggering, synchronisation and surveillance.

Finally a fault tolerant re-trigger system is needed that powers immediately all magnets in case of a spontaneous discharge in one of the generators.

7 ACKNOWLEDGEMENTS

The authors acknowledge the constant interest and support of E. Weisse, leader of the LHC beam dump project.

REFERENCES

[1] The LHC study group, "The Large Hadron Collider", CERN/AC/95-05 (LHC), CERN, (October 1995).

[2] L. Ducimetière, P. Faure, U. Jansson, H. Riege, M. Schlaug, G.H. Schröder, E. Vossenberg, "Pseudospark Switch Develoment for the LHC Extraction Kicker Pulse Generator", LHC Project Report 96-57, CERN, (September 1996).

[3] E. Carlier, L. Ducimetière, U. Jansson, M. Schlaug, G. Schröder, E. Vossenberg, "Solid State Switch Application for the LHC Extraction Kicker Pulse Generator", LHC Project Report 96-57, CERN, (September 1996).