HiLumi Inner Triplets protection

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Reliability and Availability (T. Cartier-Michaud)

T. Cartier-Michaud presented his last studies on the protection of the Inner Triplets (IT) using CLIQ and QHs. He recalled a few points:

- The protection objective is 10% probability of having at least one failure in the 4 IT in a period of 100 years, which can be translated to a 2.1% probability for a period of 20 years. We define Pme20 [%], the probability of having a main event (magnet not protected) in 20 years for the four IT.
- To be protected at **nominal current**, an IT needs 1oo1 CLIQ + 0oo8 QH **or** 0oo1 CLIQ and 7oo8 QH.
- One IT system is based on 6 identical subsystems: first half of Q1, second half of Q1, Q2a, Q2b, first half of Q3, second half of Q3.

With respect to the previous study, modifications are:

- Using a probability of failure on demand instead of a MTTF for the QDS system.
- First new design of QH trigger lines: power supplies are not monitored any more, only the charge of the capacitors
- Second new design of QH trigger lines: power supplies are not monitored any more, only the charge of the capacitors, only one trigger is used, decreasing the redundancy level of the trigger line. This design is the one used for the 11T.

New results are:

- Estimation of the MTTF for blind failure of the QDS system is difficult. In the previous study, a sensitivity analysis has been conducted, using MTTF ranging from 100 years to 1 000 000 years. Simulations showed MTTF should be greater or equal to 4 000 years. A second approach is to use a probability of mitigating a quench on demand instead of using a MTTF. Indeed, the probability of QDS not detecting a quench and/or triggering the QPS of each magnet could be proportional to the number of primary quenches and not depending on the number of hours the system has been running. In the MP3 database of quenches, we counted 2178 mitigated quenches and 0 missed quenches since the end of LS1. End of LS1 is taken as the origin because QDS has significantly changed since that date. Assuming one failure “today” leads to a probability of failure on demand of $P = 5 \times 10^{-3}$. In order for the QDS and the Quench Protection System to be responsible for half of the main event each (“balanced protection"), the QDS probability to fail on demand should be of the order of $P = 10^{-5}$, 2 decades lower than the statistics can provide. For now, simulations are conducted using a very large MTTF in order to only study the QPS, without influences from the QDS.

- Not monitoring the QH trigger lines power supplies does not change the reliability and availability results when both QH and CLIQ are used.
- Using only one trigger in the QH trigger lines and also not monitoring the power supplies do not change the reliability and availability results when both QH and CLIQ are used. Still, statistics for those simulations are quite low but using QH and CLIQ the margin is so important that we do not foresee any problem.
- The MTTF of the CLIQ PS was the only one defined by a datasheet. This value was therefore quite conservative, only 6.5 years. With respect to the logic of the system, such low value could help to increase the reliability as this component is monitored so more frequent failures imply more frequent change of CLIQ units and thus more frequent repair of blind failure of other components. MTTF from 6.5 to 21 000 years have been tested with no impact on the overall reliability.
- In order to better estimate any change in the design of QHs, simulations using only quench heaters should be performed. Because of a lack in CPU resources at CERN, no dedicated simulations have been performed yet, but simple extrapolations from past simulations could be done. These show that the protection target is far from being reached. The baseline is both QH and CLIQ so this is not an issue. Still protecting only with QH is a requirement at low current. As we used MTTF 10 times more pessimistic than historical MTTF there is room for improvement, relaxing the pessimistic assumption. Furthermore at low current only 4oo8 QHs are required to be working to protect the magnet.

During the discussion, it has been stated that:

- The time to do a slow extraction of the energy stored in the IT is below 20 min. In case chargers of CLIQ and QHs would fail, CLIQ and QH could still protect the IT during, respectively, a few hours and 20 min. Thus, if failures are detected in chargers, we can still protect the system during the whole duration of a slow extraction energy. No preventive quenching would be required.
- R. Denz explained the new design of QDS is less likely to encounter frozen FPGA channels and the monitoring has also been improved. This issue is considered mitigated.
- CLIQ was already tested, although with a design different from the final one. Unfortunately statistics and operational conditions would not help to better estimate the MTTF of CLIQ components.

Open questions:

- D. Carrillo might conduct reliability tests on prototypes of CLIQ. Inputs from the members would be appreciated. So far 3 to 18 discharges / hour into an inductive load or 2 to 9 internal discharges / hour are foreseen.

- What would be the requirement for CLIQ in order to protect at any current? (a request to quantify this came also from M. Jimenez after the meeting)
- Levels of protection have only been estimated by simulation, is it possible to ask for some actual test of the prototypes on magnets?
- Should we include the probability to quench at low current in the model? What would be such a probability?

Actions:

- T. Cartier-Michaud should run further studies:
  - (already needed but not done yet) CLIQ and QH MTTF x10 to see the increase in availability of the whole system and in particular of the QH reliability.
  - Using historical MTTF for QH or the 10 times more pessimistic values, simulations requiring 0oo1 CLIQ + 4oo8 QH should be performed to predict the reliability to mitigate quench at low current.
  - CLIQ MTTF according to Military Hand Book. This might lead to more conservative MTTF and thus lower availability. Still a bottom up approach has been asked by F. Rodriguez Mateos.
  - Using more detail assumption on the QDS, looking into redundancies, a better probability for QDS blind failure on demand could be estimated.
- Agreement on MTTFs used in each studies.
  - ⇨ T. Cartier-Michaud should run more sensitivity analysis prior to this.
- Could a short circuit in the power supply of CLIQ or QH could be propagated upstream to the current breakers and UPS?
  - ⇨ D. Carrillo will discuss with the persons in charge of UPS, in charge of connecting QH and CLIQ as well as in charge of systems in the vicinity of QH and CLIQ.
- A. Apollonio should look at Alejandro reliability studies of the 11T QH design to compare to the MTTF used by Thomas and to start the study of CLIQ components.
- It has been decided that the meeting will become recurrent every 2 weeks.

Summary of meaningful scenarios:

We define Pme20 [%], the probability of having a main event (magnet not protected) in 20 years for the four IT. For each scenario, a large range of quench rates is studied, the reported Pme20 is the worst observed on that range. The maximum tolerated for 4 IT in 20y is Pme20 = 2,1%.

MTTF and MTTR for QH and CLIQ

QH: HISTORY	PS24V	trigger	TH	charger	capacitor	strip	cur. breaker
MTTF [y]	2 100	4 200	8 400	4 200	25 200	350	700
MTTR [h]	5	5	5	5	5	Change magnet	5
# in 4 IT	384	384	384	192	1152	192	192

CLIQ: GUESS	PS24V	trigger	TH	charger	capacitor	Lead	cur. breaker
MTTF [y]	6.5	400	840	420	2 520	35 000	700
MTTR [h]	5	5	5	5	5	Change magnet	5
# in 4 IT	48	48	48	24	96	24	48

Scenario name + description	Periodic maintenance = 1y	Periodic maintenance = 3y	Periodic maintenance = 5y
1: Only CLIQ no QH QDS MTTF = 1 000 000	Pme20 = 1.24%; QR = 4/y	Pme20 = 1.57%; QR = 0.67/y	Pme20 = 2.00%; QR = 0.67/y
2: Only CLIQ no QH: scan CLIQ PS QDS MTTF = 1 000 000		Pme20 = 1.51%; QR = 1.33/y CLIQ PS MTTF 210y	Pme20 = 1.85%; QR = 0.67/y CLIQ PS MTTF 63y
11: CLIQ and QH (QH PS monitored) QDS MTTF = 1 000 000	Pme20 = 0.008%; QR = 4/y	Pme20 = 0.012%; QR = 1.33/y	Pme20 = 0.019%; QR = 0.67/y
12: CLIQ and QH (QH PS not monitored) QDS MTTF = 1 000 000	Pme20 = 0.011%; QR = 4/y	Pme20 = 0.011%; QR = 0.67/y	Pme20 = 0.018%; QR = 0.44/y
13: CLIQ and QH (11T design) QDS MTTF = 1 000 000		Pme20 = 0.006%; QR = 0.67/y (low statistics)	Pme20 = 0.019%; QR = 0.67/y (low statistics)
21: Only QH no CLIQ (QH PS monitored) QDS MTTF = 1 000 000	Pme20 =79.1%; QR = 4/y (low statistics)	Pme20 = 79.4%; QR = 4/y (low statistics)	Pme20 = 81.5%; QR = 4/y (low statistics)

Comments:

For the scenario 1), for large duration before periodic maintenance, the maximum of probability appears in the vicinity of QR = 0.67/y. The asymptotic limit for QR tends to infinity is in the vicinity of 1.35% as an increasing QR increases the detection of blind failure allowing for their mitigation and because no aging effect with respect to the number of quenches

Scenarios 2) is a study of the MTTF on the monitored power supply of CLIQ. The results are not sensitive to that parameter with respect to the error margin of results.

Scenario 11) 12) and 13) have similar trends than 1) but with probability of having a main event which are 100 times smaller. Those three scenarios require large number of simulations. Several millions of simulations have been performed and even more would be required to insure the convergence of the results on several digits. We consider the 11) and 12) scenarios to be equivalent within the error bar. Scenario 13) needs more statistics but for now we consider it as equivalent to 11) and 12) scenarios

Scenario 21) is a study of the protection level provided by QH only. Even if statistics are low, the results are clear, QH only cannot protect the IT with the parameters (MTTF) currently used.