High Energy Hadron Monitor test at Jungfraujoch High Altitude Laboratory

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Part of this programme: LHC beam dumping system reliability increase

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1. Project description

The goal of the project is building of high sensitivity HEH monitoring system for Large Hadron Collider (LHC) Beam Dumping System (LBDS). Higher sensitivity HEH measurements will allow for a more accurate estimation of Single Event Burnout (SEB) related failure rate within the LBDS as well as it will help to adapt the most appropriate mitigation measures for failure rate reduction. The testing, validation and calibration of the recently developed High Energy Hadron (HEH) monitoring system based on protected SEB phenomenon on high voltage Si diodes is a crucial step within the HEH monitor project. Testing of the system at high altitude laboratory at Jungfraujoch started in December 2018 and is part of the monitoring system calibration campaign.

The LHC beam dumping system (LBDS) is the ultimate protection system of LHC and its reliable operation is crucial for the machine protection. The LBDS consists of 50 high voltage/high current generators and their associated magnets. Its role is to deviate two counter-rotating LHC beams onto their dedicated graphite blocks which absorb the beam energy - up to 360 MJ per beam at 7 TeV. At nominal energy of 7 TeV the total current needed to deflect the beam is over 1 MA which requires to operate the generators at almost 30 kV. The LBDS pulse generators comprise altogether 800 HV thyristors and 480 IGBTs for HV trigger circuits, both sensitive to High Energy Hadrons (HEH) leaking from the tunnel via cable ducts to the galleries where the generators are installed. HV semiconductor switches can hence experience a Single Event Burnout – a catastrophic failure that instantaneously damages a semiconductor. The sensitivity of a semiconductor to HEH is expressed as SEB cross-section (SEBc-s) which is the probability of the phenomenon expressed in effective area. Any SEB on the HV components inside the LBDS generators will provoke a beam dump non synchronised with the foreseen abort gap in the beam structure and is thus associated with beam losses and the risk of damage to downstream equipment leading to significant machine down time for reparations and machine recovery. It is hence of crucial importance to reduce the probability of SEB related failure to a minimum reasonably achievable value (< 0.1 per year and beam). Measurements of the SEBc-s dependence on applied voltage of HV thyristors and triggering HV IGBT were done at CERN using in house developed non-destructive method of SEBc-s measurement with the results shown in Figures 1 and 2. Based on these measurements the SEB related failure rate probability under various present and future operation conditions was calculated as shown in Table 1. HEH fluency used in the table was calculated by Monte Carlo simulation tool – FLUKA. Thanks to the shielding campaign performed during Long Shutdown 1 (LS1), the expected HEH fluency in galleries is now down to ~ 5e4 HEH/cm2.year, which is ~ ½ of fluency of HEH from cosmic rays at earth level.

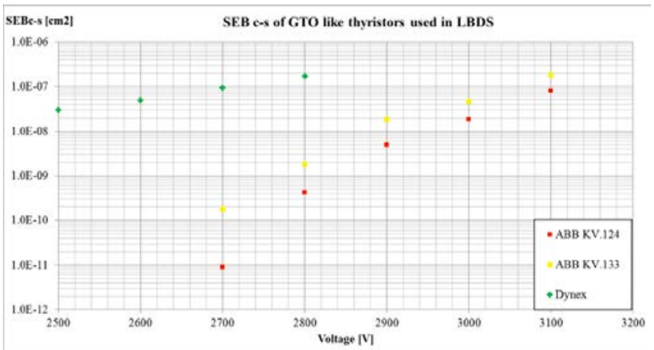

Figure 1. SEBc-s of 2 different GTO like thyristor types (both 4.5 kV rated) used in LBDS generators - Dynex and ABB made (two different production batches from ABB).

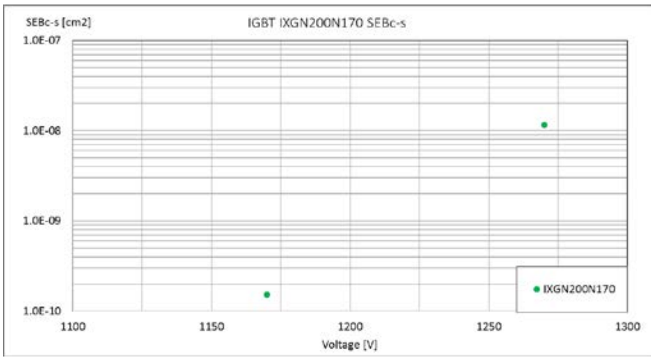

Figure 2. SEBc-s of HV IGBT IXGN200N170 (IXYS made, 1.7 kV rated) according to the measurements at CHARM.

This value is too low for presently used HEH monitors based on memory Single Event Upset phenomenon with sensitivity of one count per 3e5 HEH/cm2 and after 3 years of operation we observed 0 counts on them.

Table 1. Estimation of SEB related failure rate of LHC beam dumping generators based on SEBc-s measurement and HEH fluency simulation from FLUKA.

	6.5 TeV	7 TeV	HL-LHC@7 TeV without modif.	HL-LHC@7 TeV with modif.	7.5 TeV with modif.
	2.7 kV/GTO (MKD) 2.5 kV/GTO (MKBH)	2.9 kV/GTO (MKD); 2.7 kV/GTO (MKBH)	2.9 kV/GTO (MKD); 2.7 kV/GTO (MKBH)	2.65 kV/GTO (MKD); 2.4 kV/GTO (MKBH)	2.84 kV/GTO (MKD); 2.58 kV/GTO (MKBH)
ABB SEBc-s [cm^2]	2e-10	8e-9	8e-9	1e-10	2.5e-10
MKBH GTO SEBc-s [cm^2]	3e-8*	1e-7	1e-7	1e-11*	5e-11
IGBT SEBc-s [cm^2]	5e-9	5e-9	5e-9	3e-11*	3e-11*
HEH fluence est. [$HEH/cm^2.y$]	5e4*	5e4*	2e5 *	2e5 *	1e5 *
Failure probability					
MKD (GTO) [y^{-1}]	6e-3	0.2	0.8	1.2e-2	1.5e-2
MKD (IGBT) [y^{-1}]	9e-2	9e-2	3.6e-1	2e-3	1e-3
MKBH (GTO) [y^{-1}]	0.12	0.4	1.6	1.6e-4	4e-4
MKB (IGBT) [y^{-1}]	3e-2	3e-2	1.2e-1	7e-4	3.5e-4
Total AD (MKD GTO+IGBT) [y^{-1}]	0.1	0.3	1.2	1.4e-2	1.6e-2
Total SD (MKB GTO+IGBT) [y^{-1}]	0.15	0.43	1.7	9e-4	8e-4

In order to improve the accuracy of failure rate estimation, the HEH monitoring system based on SEB phenomenon in HV silicon diode was developed. The diode type was chosen from several candidates according to the measured SEBc-s value. High number of diodes (10 channels with 34 diodes per channel) are HV biased (~1.3 kV) and protected from destruction during SEB by dedicated protection circuit. Voltage dependence of SEBc-s of the chosen diode is shown in Figure 3 with measurement results at CHARM irradiation facility and at Am-Be source – both at CERN. CHARM is a mixed field irradiation facility capable to simulate neutron energy spectrum of interest (up to 1 GeV) well corresponding to expected spectrum in LHC galleries and to atmospheric neutrons from cosmic rays. Am-Be source is providing neutrons with energy spectrum ending at 12 MeV. Measurement of SEBc-s with Am-Be source proves sensitivity of the system down to less than 10 MeV and seems to indicate bias voltage influence to the spectral sensitivity of the HEH monitor.

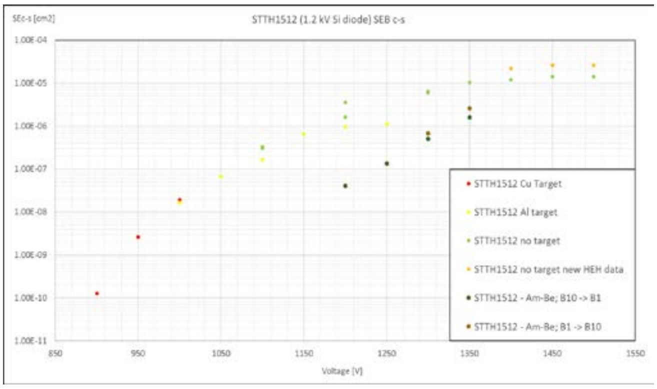

Figure 3. SEBc-s of the used HV diode (1.2 kV rated STTH1512) according to the measurements at CHARM and at Am-Be source; the later measurement is influenced by the absorption of the low energy neutrons (<12 MeV) in multiple PCBs (10) of the system under test.

At the beginning of December 2018 three prototypes of HEH monitors were installed at Sphinx laboratory with recording of the counts together with timestamp and complete telemetry into dedicated website. "Alive" signal is recorded as well with various telemetric parameters - bias voltage measurement, total current consumption, ambient temperature measurement and voltage control status. Several months will be necessary to achieve data with good statistic. After one month, we observe count rate lower than expected (factor of > 2). Possible explanation is shielding effect of the IGY monitor structure (lead + moderator) a floor above and the reinforced concrete building structure. For this reason, one monitor (No.1) was moved to NM64 laboratory on January 8th 2019 in such a way excluding potential shielding effect of the IGY structure. NM 64 lab is at lower altitude and may suffer from higher snow level on the roof (not cleaned). Observed ambient temperature is ~ 3 degree Celsius higher compared to IGY laboratory, which might slightly reduce monitor sensitivity (negative influence of temperature to SEBc-s). After few days of operation at NM64 the monitor 1 shows increased count rate compared to Sphinx lab operation but more statistics is needed to accurately evaluate the gain. If the statistically significant effect will be confirmed, moving of the residual 2 monitors to NM64 laboratory will be of interest. Future plans consist of measurement of monitor sensitivity (count rate) dependence on applied bias voltage and with help of normalised data of installed Neutron Monitors IGY and NM64 to make calibration of obtained data.

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Collaborating partners / networks

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