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# Failure analysis for liquid helium leaking to the vacuum envelope of the cryogenic distribution system of the ESS superconducting linac

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The European Spallation Source (ESS) is going to provide long-pulsed cold and thermal neutron fluxes at very high brightness. It is one of the largest science and technology infrastructure project being built on outskirt of Lund, in Sweden. Protons at 2 GeV (with a normal current of 62.5 mA) are delivered by a superconducting linear proton accelerator and are injected on a rotatory tungsten target at pulsed repetition rate of 14 Hz. The Accelerator Cryogenic Plant (ACCP) is designed to deliver the cooling power to 21 high-beta, 9 medium-beta and 13 spoke cryomodules through the Cryogenic Distribution System (CDS). In the CDS, supercritical at a temperature of 4.5 K and thermal shield gaseous helium at a temperature of 40 K are provided, while the thermal shield flow and the vapor low pressure (VLP) from the 2 K cavities are returned. The CDS consists of the three main parts: Cryogenic Transfer Line (CTL), Cryogenic Distribution Line (CDL) comprising the 30 valve boxes for the high- and medium-beta cryomodules and that for the 13 spoke cryomodules. The CDS have a total length of 385 m and a vacuum volume of 326.22 m3.

The most severe failure for the CDS is considered to be a liquid helium leak to the CDS vacuum envelope through a crack formed on a bellow. An analysis was conducted on the released flow rate from a vacuum safety device of the CDS to the accelerator tunnel. The Authors have already developed an analysis code that predicts pressure and temperature changes in the hydrogen transfer line for the ESS Cryogenic Moderator System (CMS) and its vacuum envelope. In this analysis, the helium leak from the VLP, which has the maximum inventory, to the vacuum envelope was considered and the pressure rises in the VLP and vacuum envelope were analyzed using the code. The heat load to the vacuum envelope was calculated by natural convection heat transfer and that to the process line was estimated based on CFD analysis results. The crack size (length and width) of the bellows has been determined based on the fatigue test results of the bellows.

For the small crack size, the CDS vacuum pressures did not increase up to the set point of the vacuum safety device (1.05 bar) and all the helium was discharged through a rupture disk on the process line, because of the considerable vacuum volume. For large crack size, the leaked helium is discharged into the accelerator tunnel. Due to the substantial vacuum volume, it takes 54 seconds for individuals accessing the accelerator tunnel to move away from the leak source. Consequently, continuous monitoring of the CDS vacuum pressure is essential to interlock helium supply valves from the cryoplant.

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