A PhD dissertation abstract

Modelling of the failure modes of cryogenic system in a thermonuclear reactor

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Complex cryogenic systems proliferate nowadays in many fields of modern technology. They usually contain large amounts of potentially hazardous liquefied gases, which may be very dangerous in case of uncontrolled release, resulting both in a hazard for infrastructure and presenting a lethal danger for the personnel. A very good example of a modern complex cryogenic system is a thermonuclear reactor ITER which is currently under construction in Cadarache (France). It has been designed to hold a high-temperature plasma jet (about 150 millions of Celsius degree) inside its internal chamber. This vacuum vessel in surrounded by a set of strong superconducting magnets cooled with the liquefied helium (total amount of LHe inside the cryogenic system of the reactor is about 20 tons). Any malfunction of cryogenic components located inside the ITER reactor may lead to enormous damage. A general conclusion can be drawn that the ability of failure forecasting and malfunction results estimation for a cryogenic system has a vital importance. In this dissertation an attempt of a systematic approach to this problem has been presented.

In the first part of the dissertation an idea of a cryogenic node has been introduced – such a node has been defined as typical cryogenic subsystem including typical components used in most cryogenic systems – tanks, transfer lines and valves. Over the next sections of the thesis a set of typical malfunction condition scenarios were defined and their possible consequences were listed.

In the third chapter of the thesis a quantative analysis of possible sequence of events initiated by the aforementioned malfunctions was presented. The equations describing the thermodynamical parameters of the system after occurrence of the malfunction were given (especially flow and pressure values were analysed). The simulation was intended as a tool for evaluation of values of physical parameters, especially pressure, temperature and oxygen concentration values inside specified locations of the cryogenic system under investigation.

Additionally, during numerical simulation the heat flows between the selected parts of the installation under test were computed; moreover, the mass flows caused by activation of the relief valves or by perforation of a pipe, sheet, insulation layer or cover of the investigated part of the cryogenic system were evaluated. The possible results of the malfunction in aspect of potential dangers for both the personnel and the system infrastructure were estimated.

In the fourth chapter of the dissertation the experimental attempt of verification of selected types of failure scenarios for cryogenic subsystem was described. As an example, a rupture of a pressure storage container with compressed gas was selected. A test stand including test container and data acquisition (DAQ) system was presented. The DAQ system was used for capturing of shock wave generated after controlled perforation of the pressure vessel. During the experiment a good compliance was obtained between the model featuring pressurized container detonation and the alternative model based on the TNT explosive equivalent definition.

In the fifth chapter of the thesis another experiment was discussed, during which an experimental verification of helium wave propagation inside a confined space was presented. The helium wave was generated by a controlled release of a large amount of liquefied helium into the interior of the LHC superconducting accelerator tunnel in CERN (Geneva, Switzerland). In order to measure the helium content in air a dedicated measurement system was designed and built; the system utilized ultrasonic helium detectors as sensors. During the experiment performed inside the LHC tunnel a very interesting results concerning the dynamic properties of helium cloud propagation after the initiation of the leak inside a confined space.

The results presented in the dissertation could be used as a design support tool during construction of cryogenic installations with reduced failure rate (i.e. high reliability systems). They could be also used as a set of guidance rules during creation and updating of safety rules and safety procedures related to cryogenic systems.

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