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Transient Simulations of Two-Phase Accumulator Controlled Loops

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The challenges involved in cooling Silicon trackers are well known: a radioactive operating environment, tight space and mass constraints, a need for small thermal gradients and difficulty in access to the detector zone for maintenance. Two-Phase Accumulator Controlled Loop (2PACL) based systems have proven to be successful in meeting these challenges and have thus far been used on the LHCb VELO, the ATLAS IBL tracker as well as the CMS Pixel detectors, aside from the tracker on the AMS experiment of the International Space Station.

This success has led to a growing interest in such systems, and many of the next generation of tracker detectors will adopt the 2PACL cycle for Silicon cooling. These new systems, however, have much more stringent requirements: even lower detector temperatures (<-30℃); an order of magnitude greater cooling loads (in the region of 200 kW); the need to operate several plants in parallel; even smaller cooling tubes; and the need for redundancy to deal with plant failures or maintenance.

These challenges cannot be met by the existing systems without a thorough reexamination of the system design and control philosophy. The larger volumes of the detectors to be cooled, for instance, would require impractically large accumulator vessels, and underground storage of such a large amount of CO_2 will present safety challenges.

To investigate alternative solutions, in addition to targeted experimental programmes, there is a need to develop a simulation tool capable of predicting 2PACL system behavior under a variety of steady state and transient conditions. Such a tool will enable designers to iterate through several design options and investigate the impact of different control strategies in a safe environment. It will also lead to savings in both time and money when compared to developing a dedicated prototype unit for each alternative.

The current work discusses the development of such a tool. A component-based framework has been developed in the object-oriented physical modelling platform EcosimPro. The platform has been previously used at CERN to successfully conduct dynamic simulations of cryogenic systems. The finite volume method has been used to discretize the governing conservation equations. Two-phase flow, which is of significant importance in the current application, has been pragmatically modeled using slip -ratio based void-fraction correlations.

A dedicated test facility reproducing the 2PACL architecture and specifically equipped for the current project has been used to collect data in a variety of transient conditions: system startup, step change of temperature set point, step change of the cooling load and finally, system shutdown. These conditions have been simulated using the component-based modeling framework presented here, and preliminary verification and validation results are discussed in what follows.

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