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Ph.D. thesis description

Non-linear Model based Predictive Control (NMPC)

of the

Large Hadron Collider's (LHC) Super fluid Helium Cryogenic Circuit

Keywords
non-linear model based predictive control (NMPC), EcosimPro, distributed parameter system (DPS), cryogenics, super fluid helium

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Timeframe
Project is expected to finish in 36 months time starting on March 1, 2008

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1. Introduction

The Large Hadron Collider (LHC) at CERN will be the newest, largest and highest energy particle accelerator and collider in the world when switched on in May 2008. It consists of more than 1600 superconducting magnets that are maintained at operational temperature equal to 1.9K by the Super fluid Helium Cryogenic Circuit.

The experiments performed on the String and String2 LHC Prototypes from 1995 to 2003 showed that the regulation of the LHC magnets temperature is a challenge, mainly due to presence of strong nonlinearities together with frequent changes of the operation point, inverse response on the control input manipulation and variable dead time of the response, huge quantity of such loops that, failures of sensors or hydraulic components, etc.

A PID controller used to control the temperature had poor performance. A MPC controller was developed, tested and showed a great potential to improve the temperature control of the first 53 meter long "Half Cell" String Prototype. Unfortunately the MPC controller could not be commissioned on the 107 meter long "Full Cell" String2 Prototype because of the mismatch between the distributed parameters process and its lumped parameter model used in the controller.

An improved, “first principle" nonlinear distributed parameters model of the circuit has been developed in frame of the Master Thesis Final Project under name "Modeling and control of the String2 LHC Prototype at CERN" in time period from March 1, 2007 to August 31, 2007. The model is not complete and needs further developments to enable the successful implementation of the NMPC approach to the control of the Super fluid Helium Cryogenic Circuit.

2. Targets

The aim of the project is to develop, test in simulation, install, tune and validate an advanced controller for the Super fluid Helium Cryogenic Circuit, first of all of the LHC Standard Cells and then of a full sector.

3 Development

3.1 Modeling

Two kind of models are required for the study:

- a full model of the process that can substitute the process for studies and tests
- a simplified model to be used in the NMPC

In order to enable the development of the NMPC controller (online optimization of control actions), a fast, distributed parameters model of the Super fluid Helium Cryogenic Circuit of a LHC Standard Cell has to be finalized. In the following part the steps necessary to obtain such a model are listed.

3.1.1 Improvements of the “first principle” distributed parameters model

The “first principles” distributed parameter model developed recently is not completed. In order to get a good base for future improvements the model must be complete. The modeling of super fluid helium distribution in the Bayonet Heat Exchanger needs reviewing and the modeled cooling loop has to be closed – the temperature of the supercritical helium arriving to the JT valve must be computed.

An investigation of the behavior of the model at higher heat loads is also needed in order to explain the differences observed during simulation of the String2 phase2 prototype.

3.1.2 Optimization and validation of the model

Based on the experimental data from the LHC Standard Cell, the model parameters will be optimized using various optimization techniques in order to calibrate the model. The validation of the model will take place next.

3.1.3 Creation of the Standard Cell Library in EcosimPro

The simulation will be performed in the state-of-the-art EcosimPro environment. In order to extend the model of the Super fluid Helium Cryogenic Circuit from the single Standard Cell to the complete LHC sector, the library containing the sector components will be created in EcosimPro.

3.1.4 Creation, optimization and validation of the the complete LHC sector model

Interconnecting the Standard Cell Models from the Standard Cell Library created in the previous step, the complete LHC sector model can be built easily. The model, and mainly interconnections between the Standard Cells can be optimized in this configuration an the model has to be validated against the experimental data from the LHC.

3.2 Control

The aim of the project is to develop a NMPC Control strategy for the distributed parameter Super fluid Helium Cryogenic Circuit. That involves a creation of controller that computes the optimal control input of a Standard Cell Cryogenic Circuit regarding state of whole Sector Cryogenic Circuit.

3.2.1 Development of the simplified process model

This will be probably the most important and difficult part of the project.

Due to the complex dynamics of the distributed parameter system, the first principles model is expected not to be adequate to enable the very fast simulation of the process needed to perform the online optimization of the NMPC controller action.

That is why a simplification of the model must be performed in order to obtain a fast and robust model applicable as an internal model in the NMPC controller.

The simplification of the model is supposed to be achieved by:

- reduction of the PDE’s governing the system behavior
- conversion of some parts of the first principles model into black-box elements, e.g. the heat transfer between the Inner Pipe and the Magnets
- simplification of the complex internal structure of the process, corresponding to the most important process characteristics, using for example 2 component (wetted-dry) model of the Bayonet Heat Exchanger
- converting the model using subspace projection approach

The simplified models will be used for control purposes as a NMPC internal model, and the controller can be tested in simulation against the full size first principles model.

3.2.2 Development of the NMPC algorithm

In the next step the NMPC control algorithm has to be developed. The algorithm has to calculate the optimal control input for the assembly composed from interconnected Standard Cells. It will follow previous approaches based on an internal model in EcosimPro linked with an optimization algorithm. The NMPC will be tested in simulation with the full model of the process.

3.2.3 Installation of hardware and software on 3 neighbor sectors

The control strategy should be implemented (the hardware and software have to be installed) on at least 3 neighbor sectors in order to consider the sector interactions and make possible the final test of the controller in the real world conditions.

3.2.4 Tuning and validation of the controller

The controller has to be tuned and validated in order to get the green light for enhancing the existing PID control with the advanced NMPC technique around whole 27 km circumference of the LHC machine.

3.2.5 Robustness against system failures

The controller has to be investigated in order to understand how it cope with failures of measuring instruments or failures on piping like an interrupted liquid supply in the bayonet heat exchanger.