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A PID based MIMO control system of the CMS Tracker thermal screen

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***Abstract* – The Tracker is one of the CMS (Compact Muon Solenoid experiment) subdetectors to be installed at the LHC (Large Hadron Collider) accelerator at CERN (European Organization for Nuclear Research). The tracker will be operated at a temperature of –10 °C in order to reduce the radiation damage on the silicon detectors; hence, an insulated environment has to be provided by means of a screen that introduces a thermal separation between the Tracker and the neighbouring detection systems. The control system design includes a description of the process by means of a thermodynamic model and the electrical equivalence. The transfer function is inferred by the ratio of the temperature outside the tracker and the heat generated (which is the controlled variable). A PID (Proportional Integral Derivative) controller has then been designed. The MIMO (Multiple Input Multiple Output) approach and the Relative Gain Array showed that mutual interactions are negligible.**

The results achieved so far prove that this methodology is rigorous and effective; every step of the procedure is well defined, simplifying the debugging and updating phases. Besides, the first field tests show a good accordance of the model to the real system.

I. INTRODUCTION

The Tracker extends over a cylindrical region of 2.4 m in diameter and 5.6 m in length. The whole volume will be at -10 °C temperature, in order to minimize the radiation damage effects on the silicon detectors [1].

The main task of the thermal screen is to introduce a thermal separation between the Tracker and the neighbouring detection systems. The active thermal screen is made of one heating and one cooling surface separated by a layer of insulating material. The heat flow, naturally due through a surface separating the two volumes at different temperatures, is artificially produced on one side of the screen and removed on the other side. The control, i.e. the desired profile of the regulated temperature, is produced by heating the foils via a power supply driven by an analog output module of the PLC (Linear Output Control). The quality of the thermal insulation is dependent on the accuracy of the control. We will deal with three main subjects: Modelling the system; designing the PID controller; implementing the PID into the PLC, describing the process as a Finite State Machine and running tests.

The heating panels are standard Kapton foil with an etched circuit, produced in the dimensions 0.45x0.6 m for the specified resistance of 61 Ω (140 W/m^2 @ 48 V); the cold plate is made of two thin aluminium sheets (0.7 mm thick each) joined together in such a way as to produce a spiralling channel through which the cooling liquid flows.

II. MODELLING AND DESIGN

The theoretical approach presupposes the knowledge of the physical laws of the process, i.e., a lumped thermodynamic description, as shown in Fig. 1. Some approximations have naturally to be made in order to be able to establish those differential equations, e.g. considering the innermost tracker volume at constant temperature. The electrical equivalence is shown in Fig. 2; it is derived by substituting the heat source with a current source and the cold plate with a constant voltage generator. The temperature on the outer skin is considered as a variable voltage. The transfer function is defined by the ratio of the voltage on the outer skin and the voltage input, i.e. the ratio of the temperature outside the tracker and the temperature of the heating panel.

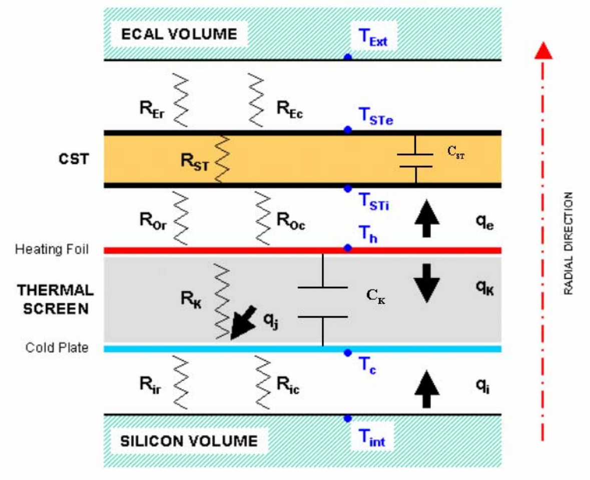

Fig.1 Thermal screen thermodynamic model

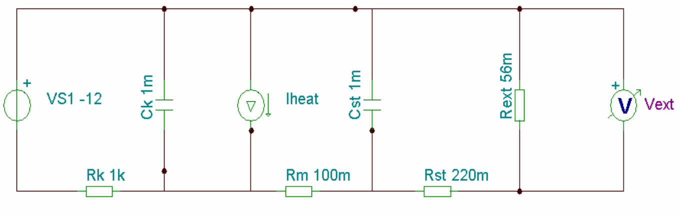

Fig.2 Electrical equivalency

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$$G(S) = \frac{V_{Ext}}{I_{Heat}} = \frac{0.0332}{S^2 + 29.17 \cdot S + 111.9 \cdot S}$$

Eq.1 Transfer function

The process analysis (both in frequency and time domain) deals with performances and stability issues: the system shows non-optimal phase and gain margins, low static gain and high steady-state error. In order to achieve stability and satisfy system performances [2][3], a PI controller has been designed: a value of K_P=16400 has been chosen for the proportional term. The integrator adds a pole in the origin and a zero in -1.2, which results in an integral term K_I=0.02. The controller architecture is parallel, as in the PLC algorithm. The new system behaviour is shown in Fig. 3.

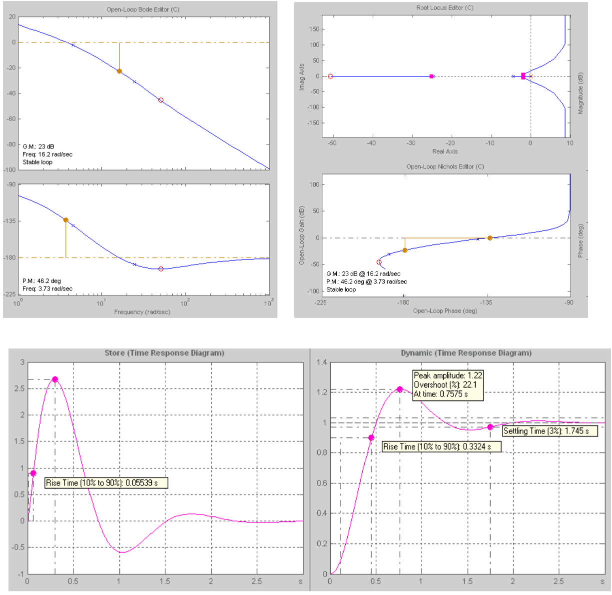

Fig.3 System performances

The 32 panels of which the thermal screen is made are prone to show mutual interactions: since they are arranged in a cylindrical fashion, each one of them will at least feel the influence of two neighbours on the long side, and one on the short side. Therefore, the system can be considered a MIMO (Multiple Input Multiple Output) one; the interaction on the short side is assumed to be negligible, which makes the system a classical 2x2. Studying the Relative Gain Array, the system shows a small transmission interaction ($0 < \lambda_{ij} < 1$). Also, being the controller logic fully implemented in the PLC, no decoupling has been foreseen, and final tuning has been performed on field. The Finite State Machine (FSM) has been designed using the Stateflow language, and then embedded in the PLC code.

As shown in Fig. 4, the starting point (and default state) is "off". Two alarm classes have been defined: warning (Level 1) and severe alarm (Level 2) which, in turns, can call interlocks either on the Tracker or on the ECAL side or both.

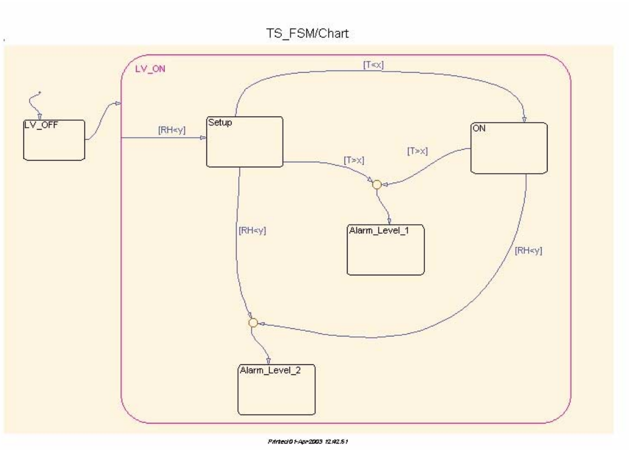

Fig. 4 Stateflow diagram

III. CONCLUSIONS

The methodology hereby introduced and adopted has shown to be effective and time saving; in fact, it allows an easy interaction between control engineers and physicists in charge of the design and operation of the systems, thanks to a theoretical (the thermodynamic model) and visual (Finite State Machine, grafcet) description. The rigorous approach in the modelling let the designer cope with every change in the project specification, while the transfer function allows a very fine tuning of the PID. The tests performed with the PLC show a good accordance to the results expected. Since the system is a MIMO process, interactions among the 32 control loops have been taken into account, and the mutual influence has been considered negligible.

IV. ACKNOWLEDGMENTS

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V. REFERENCES

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