10th ICALEPCS Int. Conf. on Accelerator & Large Expt. Physics Control Systems. Geneva, 10 - 14 Oct 2005, PO2.002-2 (2005)

LHC GCS PROCESS TUNING: SELECTION AND USE OF PID AND SMITH PREDICTOR FOR THE REGULATIONS OF THE LHC EXPERIMENTS' GAS SYSTEMS.

S.Cabaret[1], R.Barillère[2], A.Rachid[3], H.Coppier[4].

[1]UPJV / LMBE-ESIEE, Amiens, France – CERN, Geneva, Switzerland;
[2]CERN, Geneva; Switzerland;
[3]UPJV, Amiens, France; [4]LMBE-ESIEE, Amiens, France;

ABSTRACT

The LHC experiment's Gas Control System (LHC GCS) has to provide LHC experiments with homogeneous control systems (supervision and process control layers) for their 23 gas systems. The LHC GCS process control layer is based on Programmable Logic Controllers (PLCs), Field-Buses and on a library, UNICOS (UNified Industrial COntrol System). Its supervision layer is based on a commercial SCADA system and on the JCOP and UNICOS PVSS frameworks.

A typical LHC experiment's gas system is composed of up to ten modules, dedicated to specific functions (e.g. mixing, purification, circulation). Most of modules require control loops for the regulation of pressures, temperatures and flows or ratios of gases. The control loops of the 23 gas systems can be implemented using the same tools, but need specific tuning according to their respective size, volume, pipe lengths and required accuracy. Most of the control loops can be implemented by means a standard PID (Proportional, Integral and Derivative) controller. When this is not appropriate the Smith Predictor can be used as an alternative.

This paper will describe the limitations of a standard PID approach as well as the results of the Smith Predictor implementation when a PID controller is insufficient. It will also explain the feasibility, identification, testing and the conclusions of both approaches.

INTRODUCTION

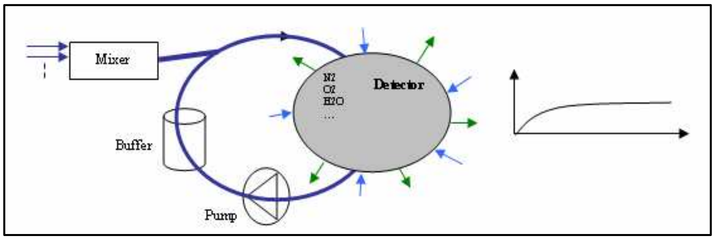
The gas systems developed for the LHC has been designed to satisfy the experiments' requirements. Reliability and stability are two critical points for physicists and any variation in the gas composition can affect the accuracy of the acquired data.

The gas systems have several control loops: Ratio, Pressure, and Temperature. The most critical control loop deals with the pressure regulation. An accurate pressure regulation is required for good physic data. In addition, depending on each sub-detector the pressure has to be within a specific range to prevent damaging the system.

The control system in GCS provides a basic control loop strategy using the PID approach. In more than 80% situations, this control algorithm is sufficient to solve stability and reliability problems. However, PID limitations exist and new strategies have to be taken into account. The Smith predictor is one such strategy.

PRESSURE CONTROL LOOP

A gas system should provide and maintain a combination of gases inside the detector chambers. Several hardware modules can be added inside this process: the mixer, the distribution, the pump, etc. The objective is to have the correct composition after a certain time in order to provide the physicists with a reliable and stable mixture. The solution developed is based on a constant input mixture flow which renews the detector gas composition. The flow provides a constant differential pressure along the gas circuit.



Since most detectors are different (design, dimension, weight, etc.) and their gas systems are pressure regulated it follows that these systems must be adapted to the detectors and thus have specific needs in terms of control loops. By modeling the pressure control loop system we can obtain a representation of the regulation performance. The regulation performance (speed response, accuracy etc.) is directly dependant on the control loop configuration. Because data acquisition depends on pressure variation, any control loop implementation and tuning have a direct impact on the physics measurement and reliability. The general recommendation is not to exceed the specified threshold by more than 1 mbar. Thus, it is easy to see how the regulation approach is crucial for the gas systems.

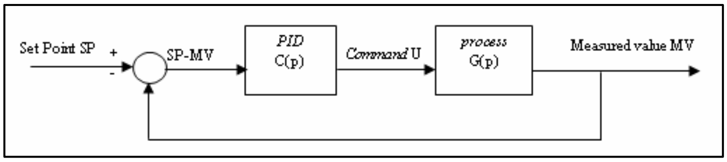
PID APPROACH

Introduction to PID tuning principle

PID corrector is the most common control loop solution used in the industrial processes. It provides a robust regulation solution for 80% of systems. This corrector is placed before the process and acts on it.

The PID is a causal approach. The basic formula under Laplace is:

$$C_{PID}(p) = G_{PID}(1 + \frac{1}{T_i p} + T_d p)$$



$$H_{OpenLoop} = C_{PID}(p).G(p); H_{CloseLoop} = \frac{C_{PID}(p).G(p)}{1 + C_{PID}(p).G(p)}$$

Each PID action acts on the overall system response (accuracy, stability, ect). Here is a brief summary of the actual impact of each parameter:

Gain (G): a big value increases accuracy and the speed of the response but decreases the stability.

Integral Time (Ti): a bigger value slows the system response, decreases the stability but increase the accuracy.

Derivative Time (Td): a bigger value increases the speed of the system response but decreases overall system performance. This parameter is mainly used to compensate the time delay (process latency).

The PID tuning consists in finding an appropriate combination of G, Ti and Td in order to provide the necessary closed loop response. The PID tuning is chosen according to the system order and properties. Usually, first order, second order and unstable systems can be considered. The process determination is both the most complicated and crucial point in a regulation problem. Several ways of development can be followed to provide an installation model.

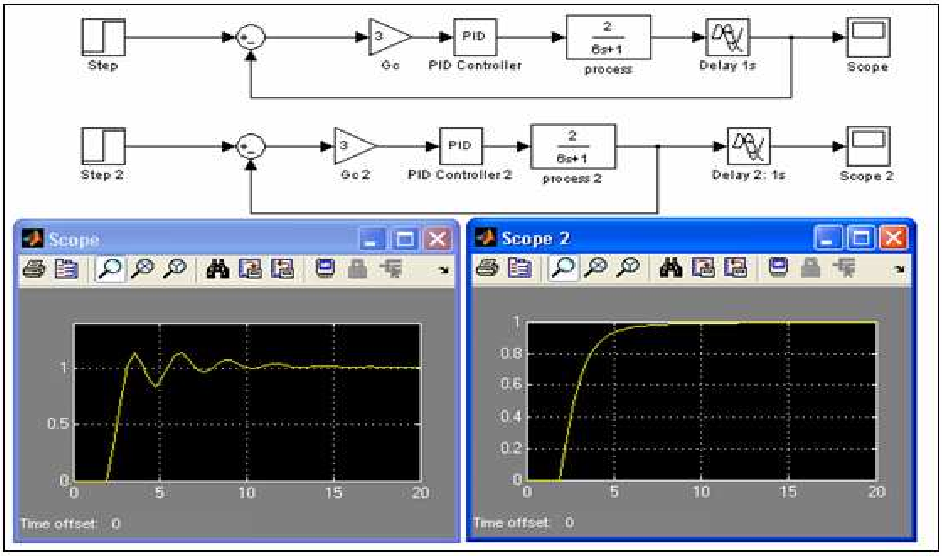
$$G_{FirstOrder} = \frac{G_s}{1 + Tp}; G_{SecondOrder} = \frac{G_s}{1 + a_1 p + a_2 p^2}$$

These equations can be easily used with a PID approach to provide quick response with the desired performance. An example of a desirable first order response with a stable first order process is:

$$H_{ClosedLoop} = \frac{1}{1 + T' p}; T_i = T; T_d = 0; T' = {}^{T_i}\!\big/_{G_c.G_s}$$

PID limitations

The time delay is the system reaction latency after an input change. The PID limitations come mainly from the delay inherent in the system. If the time delay is included in the closed loop, the system response is directly affected (less stability) whereas if the delay is not inside the closed loop structure the closed loop response is just postponed.



Delay influence in two close loop approaches with PID's (Simulation under Matlab-Simulink)

Here is an example of a first order system with delay and its PID rules and limitation:

$$G_{FirtOrder\_Delay} = \frac{G_s.e^{-\tau p}}{1+Tp}$$

T/τ>20: On/Off regulation; 10<T/τ<20: P action only; 5<T/τ<10: PI actions only; 2<T/τ<5: PID actions; T/τ<2: PID not applicable

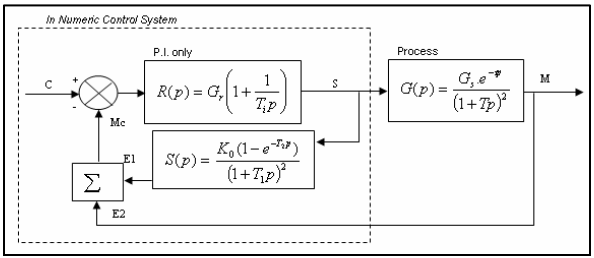
The process latency is a real problem in the determination of the parameters for the PID. When the delay exceeds T/2, a closed loop system with a PID is not appropriate.

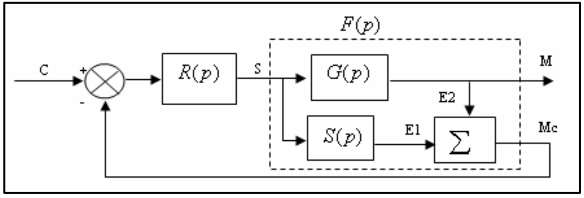
THE SMITH PREDICTOR

The Smith Predictor consists of building a corrector which virtually hides the time delay in the closed loop response of the process. It is basically a mix of a PID corrector with an internal model. The aim of the corrector is to provide a virtual system without time delay to the PID. Obviously the Smith Predictor model takes into account the time delay in order to do this.

Principle

The Smith Predictor model can be used for a first order, a second order (double pole) or an unstable system with delay.





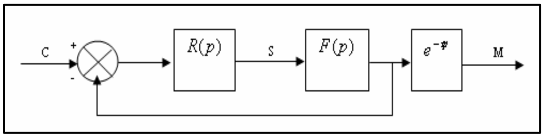
Second order:

$$G_{process}(p) = \frac{Gs.e^{-\tau p}}{(1+Tp)^2}$$

F(p) is the transfer function seen by the PI:

$$F(p) = G(p) + S(p) = \left.\frac{G_s}{(1+Tp)^2}\right|_{\substack{K_0=G_s \\ T_1=T_i=T \\ T_2=\tau}}$$

The system can be described by:

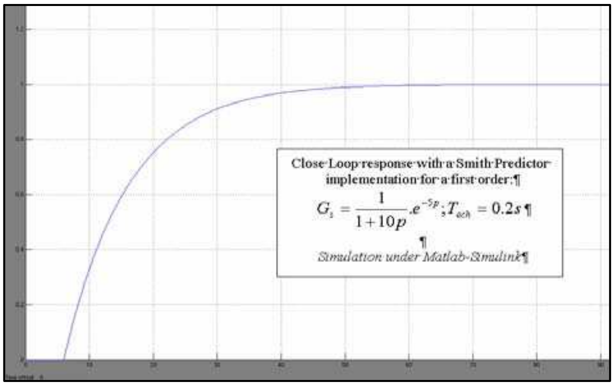


In closed loop we obtain the desired response:

$$H_{CloseLoop}(p) = \frac{1}{1 + ap + bp^2}; a = \frac{T}{G_s.G_r}; b = \frac{T^2}{G_s.G_r}; z = \frac{a}{2\sqrt{b}}$$

Limitation

In theory the Smith Predictor works correctly and gives the desired closed loop response in simulation. Here are two simulations for a first order system and a second order system both with a time delay of 5 seconds:

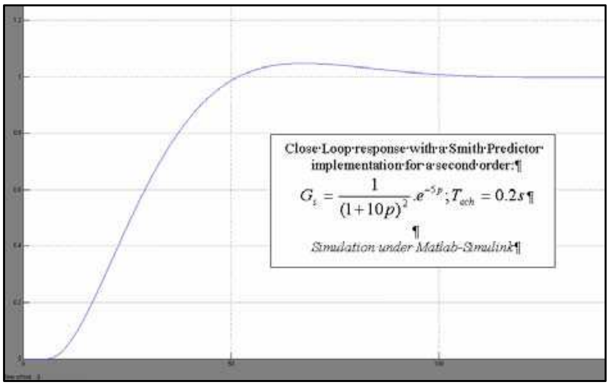


Close Loop response with a Smith Predictor implementation for a first order:¶

$$G_s = \frac{1}{1+10p}.e^{-5p}; T_{ech} = 0.2s$$

¶

Simulation under Matlab-Simulink¶



Close Loop response with a Smith Predictor implementation for a second order:¶

$$G_s = \frac{1}{(1+10p)^2}.e^{-5p}; T_{ech} = 0.2s$$

¶

Simulation under Matlab-Simulink¶

The Smith Predictor takes advantage of using PID by removing the effect of the delay inside the closed loop response. Limitations of this model-based control loop approach are related to the closed loop response we desire. This is due to the Smith Predictor implementation which fixed the PID actions. That means for a system the Smith Predictor has only one correct set of tuning parameters. Moreover it is obvious that a process represented by a first order with delay is not exactly equivalent to the real installation.

PLC IMPLEMENTATION

A PLC has many possibilities. However on advanced control approach is not always well-developed inside available libraries. PIDs are often the main control loop used and new advanced control loop implementations must often be developed for dedicated applications.

PLC advanced control based on a model

First possibility: PLC is a numeric control system. The first possibility to implement a Smith Predictor is to use the discrete approach (in z).

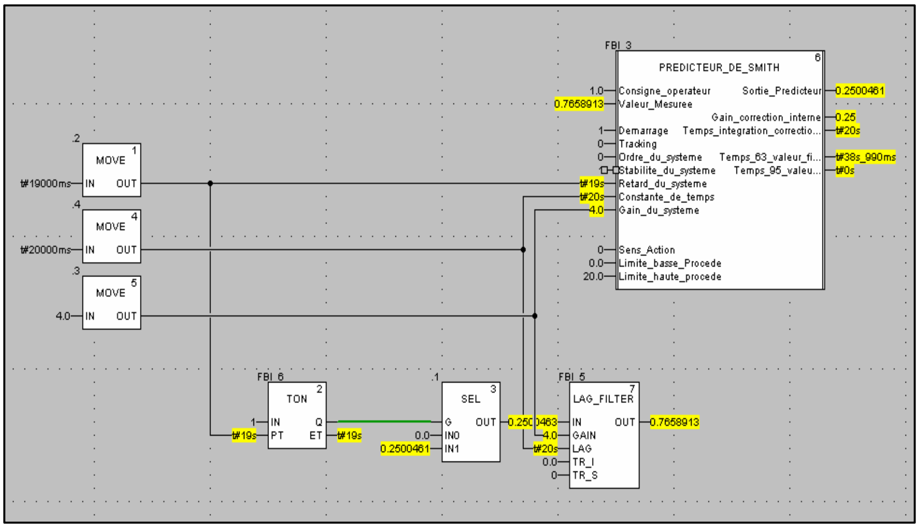
$$G(p) = \frac{G_s}{1+Tp}; G(z) = \frac{b_1 z^{-1}}{1+a_1 z^{-1}} = \frac{S(z)}{E(z)} \Leftrightarrow S(z)(1+a_1 z^{-1}) = E(z) b_1 z^{-1}$$

The following recursive equation corresponds to the discrete representation of a first order system without time delay:

$$S_k + a_1 S_{k-1} = b_1 E_{k-1} \Leftrightarrow S_k = -a_1 S_{k-1} + b_1 E_{k-1}; a_1 = -e^{-T_e/T}; b_1 = G_s\left(1 - e^{-T_e/T}\right)$$

Then by using this equation and taking in account the previews states (input-system response), the Smith Predictor can be developed. This implementation needs to compute for each application the execution time T_e.

Second possibility: The PID controller is the main control loop block provide by a PLC library. It is also possible to use special function blocks to build a Smith Predictor. In Unity (Schneider) the first order, second order and integrator block are in the default library. This gives a real advantage by not taking into account the inherent discrete approach of the first possibility. The Smith Predictor can be either implemented directly in the logic or implemented by creating a functional block (FBD). This possibility has the advantage to ignore the execution time T_e.



First order simulation with a Smith Predictor function bloc

Result under Unity

The Smith Predictor Function Block allows three possibilities: working with a first order, a second order (double pole) or a unstable system. All the system parameters must be specified (Time constant, Delay, Gain) and thanks to auto tuning the Predictor gives a command to the actuator input. The main advantage of creating a dedicated function block for advanced control is the repeatability and auto tuning possibilities. The Smith Predictor function block takes the system parameters and directly implements the correspondent PI actions needed inside the model.

INTEGRATION IN LHC GCS FRAMEWORK

The PLC implementation is just a first step in the LHC GCS integration process. A new device or a new function block (or a new functionality) has a direct impact on the LHC GCS framework [6][7][8]. Today the Smith Predictor is not integrated. A new function block under UNICOS must be created; a new widget under PVSS; a new development under the instance generator; etc. The Smith Predictor must be integrated at each level of the LHC-GCS Framewok [7] and Model-Driven [8].

PID VS SMITH PREDICTOR CHOICE

Process Identification

The process should always be modeled mathematically. Actually process identification is the main difficulty for the GCS. Installations are designed with different sizes and volumes. This results in having different system parameters (time constant, delays, and order) for each control loops of each gas system. There are three possibilities to find the transfer function of a system:

a. Based on Model Knowledge methods
b. Based on Empirical methods
c. Based on Parametric Identification methods

The first method is difficult to determine for the GCS. The third method is probably the best solution if the identification model driven is coherent (and if the require time for testing is sufficient).

The second possibility based on empirical methods is the most common and quick approach to start with.

Regulation type choice

When the transfer function has been identified, the regulation type can be chosen. The choice of the regulation type is based on the system stability, the system order and the time delay.

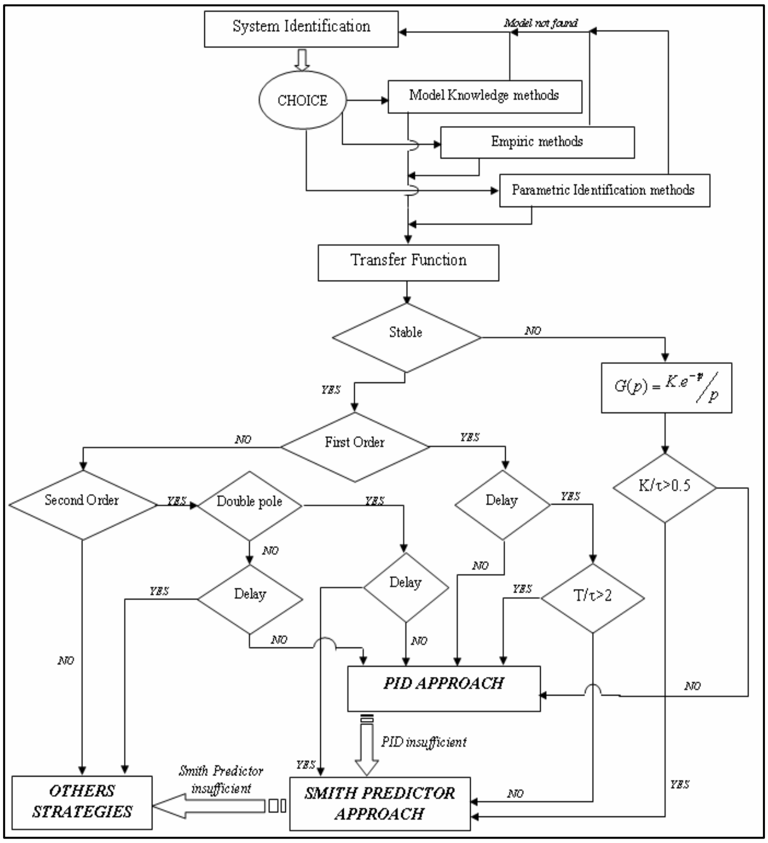


Fig. 1

CONCLUSION

The PID is the most commonly used control loop in the industry but the Smith Predictor is a new and simple approach which can solve many regulation problems.

Gas process experts sometimes may not be able to tune their regulation using a PID solution. The Smith Predictor in UnityV2 presents an alternative solution. The pressure control loop inside the sub-detectors is the most critical regulation for the reliability and stability of the gas system. The Smith Predictor will increase the possibilities offered to the Gas Experts. The main difficulty concerns the process identification. By going through the decision flow chart, the gas experts will have a systematic procedure to choose a control loop solution. This process is not only available for the pressure regulation of the gas systems but for all control loop regulation. The others strategies (Fig. 1) after the Smith Predictor include Adaptive Control, Global Predictive Control, Fuzzy Control etc.

Thus, the Smith Predictor integration into the LHC-GCS framework is under discussion.

REFERENCES

[1] Pigeron B., Mullot H., Chaix A., Felix L., Aubert Y. *BOUCLES DE REGULATION* – Etude et mise au point, 3^{e} édition, Bhaly Autoédition, 1996

[2] Granjon Y., *AUTOMATIQUE – Systèmes linéaires, non-linéaires…*, Dunod, Paris, 2003

[3] Landau I.D., *Commande des systèmes – conception, identification et mise en œuvre*, Hermes Science Publication, Paris, 2002

[4] The LHC GCS project, http://itcofe.web.cern.ch/itcofe/Projects/LHC-GCS/

[5] P. Gayet et al., “UNICOS a framework to built industry-like control systems, Principles and Methodology”, ICALEPCS’2005, Geneva, Switzerland, October 2005.

[6] R. Barillère et al., “LHC GCS: A homogeneous approach for the control of the LHC experiment gas systems”, ICALEPCS’2003, Gyeongiu, Korea, October 2003.

[7] G. Thomas et al., “LHC GCS: A framework for the production of 23 homogeneous industry-like control systems”, ICALEPCS’2005, Geneva, Switzerland, October 2005.

[8] G. Thomas et al., “LHC GCS: A Model-Driven approach for the automatic PLC and SCADA code generation”, ICALEPCS’2005, Geneva, Switzerland, October 2005.