C3Po1A-08 [17]: Control of Warm Compression Stations Using On-line Model Predictive Control (MPC): Experimental Results

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Abstract

This poster deals with multivariable on-line model predictive control (MPC) for helium Warm Compression Stations (WCS). During WCS operation, control algorithms must ensure that the constraints are respected. These constraints can be imposed by the system itself (valves open from 0 to 100% compressor maximum current and pressure, …), or imposed by the users (valves which must remain closed or open to a minimum other than 0, pressures which should not be too low or too high). The MPC controller takes into account the constraints and set points into one optimization problem, which makes it the ideal candidate to control the WCS. The papers presents experimental results obtained on the SBT WCS, showing that the WCS is running safely while taking into account the constraints. The experimental tests shows that using MPC leads to high stability and fast disturbance rejection such as those induced by a turbine or a compressor stop, which is a key-aspect in the case of large-scale cryogenic refrigeration. The proposed control scheme can be used to achieve precise control of pressures in normal operation or to avoid reaching stopping criteria (such as excessive pressures) under high disturbances (such as the pulsed heat load expected to take place in future fusion reactors).

Main objective

The aim is to replace PI controllers that do not take into account coupling between regulated variables and multivariable LQ controllers which are not allowing manual mode for actuators.

Constrained Model predictive Control is chosen as the core of the control strategy as it takes into account coupling between regulated variables and allow manual mode for actuators through inputs constraints

Model of the warm compression station

To generate Model Predictive Control : a model of the system is needed to predict its future behavior. The model is made with Simcryogenics for Matlab/ Simulink

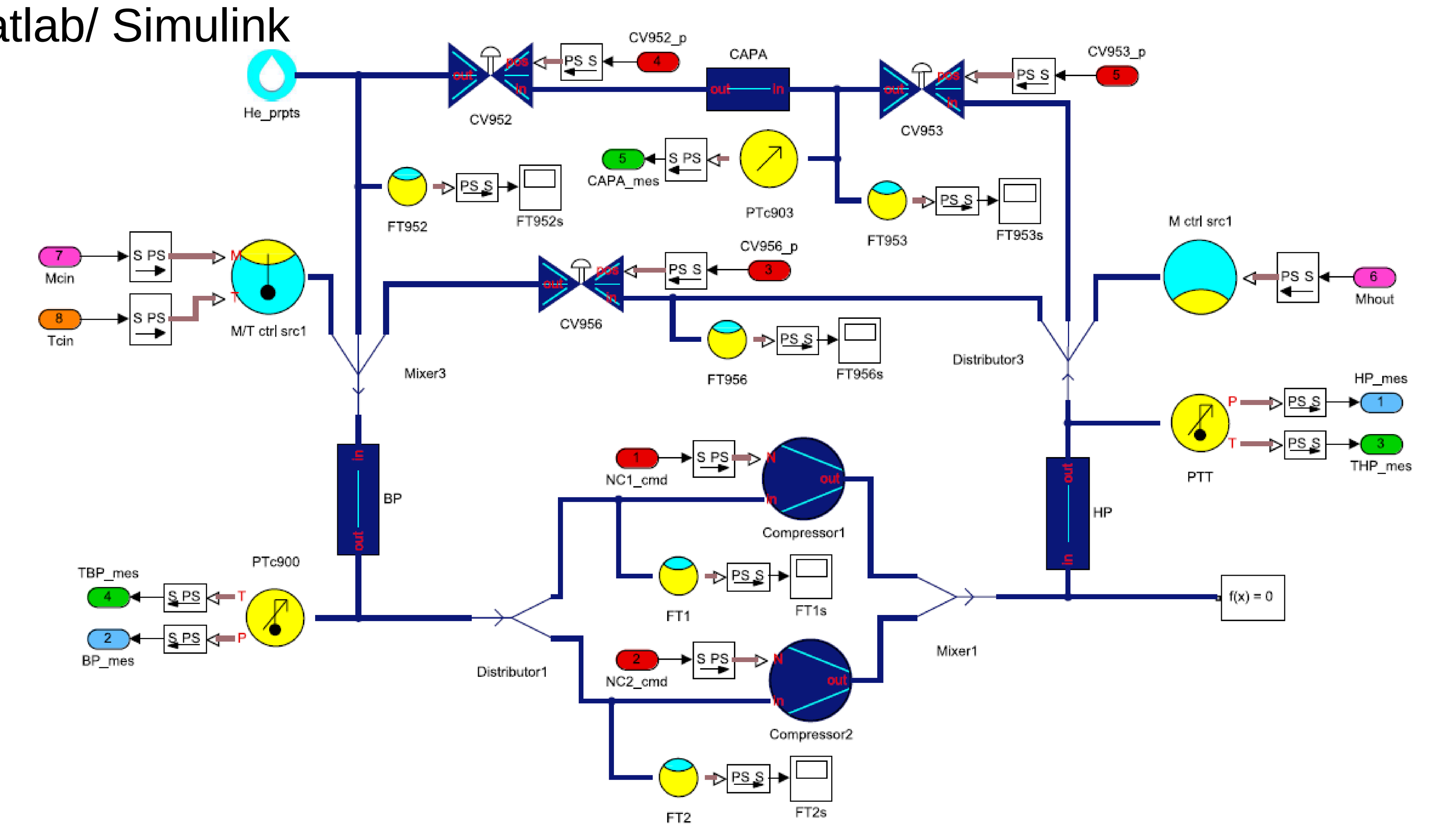


Figure 1: System is modeled with the **Simcryogenics library developed by DSBT.**

This model will be used for the control scheme validation. To synthesize MPC, we will use a linearized model. Matlab takes care of the linearization and gives us the model of the following form :

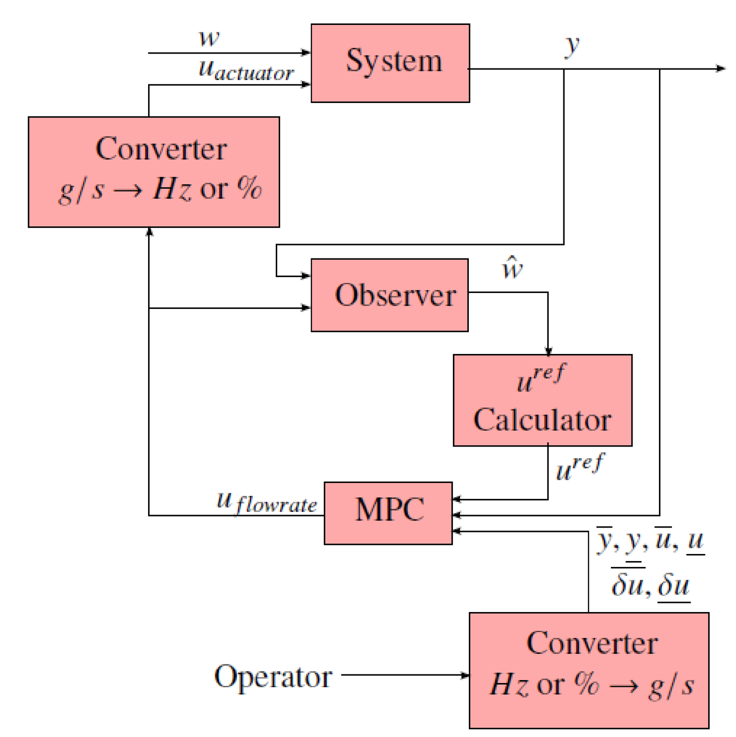
$$\dot{x} = Ax + Bu + Fw$$

With x the state (pressures), u the control effort (actuators), and w the disturbances (inlet and oulet flowrates of the cold box).

Command architecture

The control strategy is divided into several blocs:

- **Observer** : It estimates the inlet and outlet flowrate
- **Ref calculator** : it calculates the input that stabilize the system
- **Converters** : they convert actuators flowrates into g/s, or the opposite
- **MPC** : the block that actually controls the system



u^{ref} is generated such as the system is stabilized i.e. : $\dot{x} = 0$

Flowrate observer : simulation

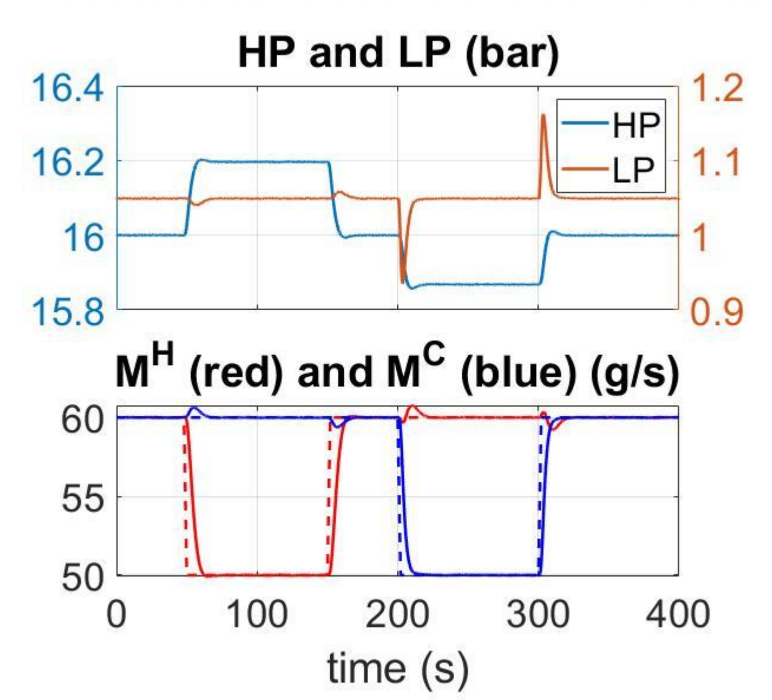


Figure 2: Observer is tested with linearized model : the inlet and outlet flowrates are correctly estimated

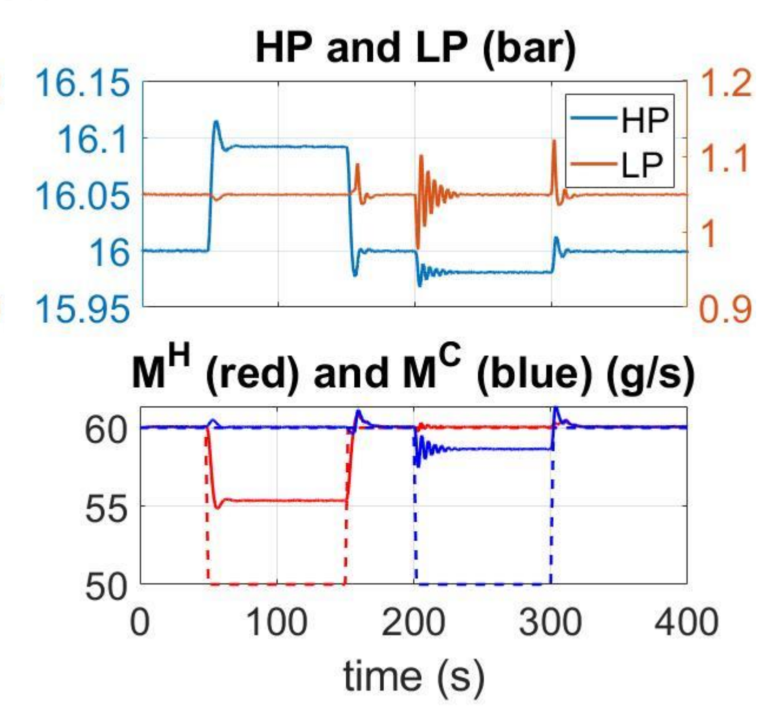


Figure 3: Observer is tested with nonlinear and voluntarily inexact model : the flowrate estimation is wrong but it stills **stabilize the system**

MPC synthesis and resolution

The model predictive controller is derived by minimizing the following formula :

$$\min_{u(i)} \sum_{i=k}^{N+k} \left(x(i) - x_{ref}\right)\Big|_Q^2 + \left(u(i) - u_{ref}\right)\Big|_R^2$$

Where N is the prediction horizon, and x_{ref} the set point to be tracked. By minimizing this function, we ensure that the set point is tracked correctly. To ensure that the result make sense, this formula is minimized with constraints both on u and x:

$\underline{u} < u < \bar{u}$ → actuator constraint i.e. valve 0/100 % and C1 35/55 Hz
$\underline{x} < x < \bar{x}$ → pressure constraints HP 12 / 18 bars BP 1/1,1 bar

This minimization problem under constraints is solved by a solver developed at dSBT that runs on a M580 PLC. The sampling period of the controller is 250 ms.

Experimental results

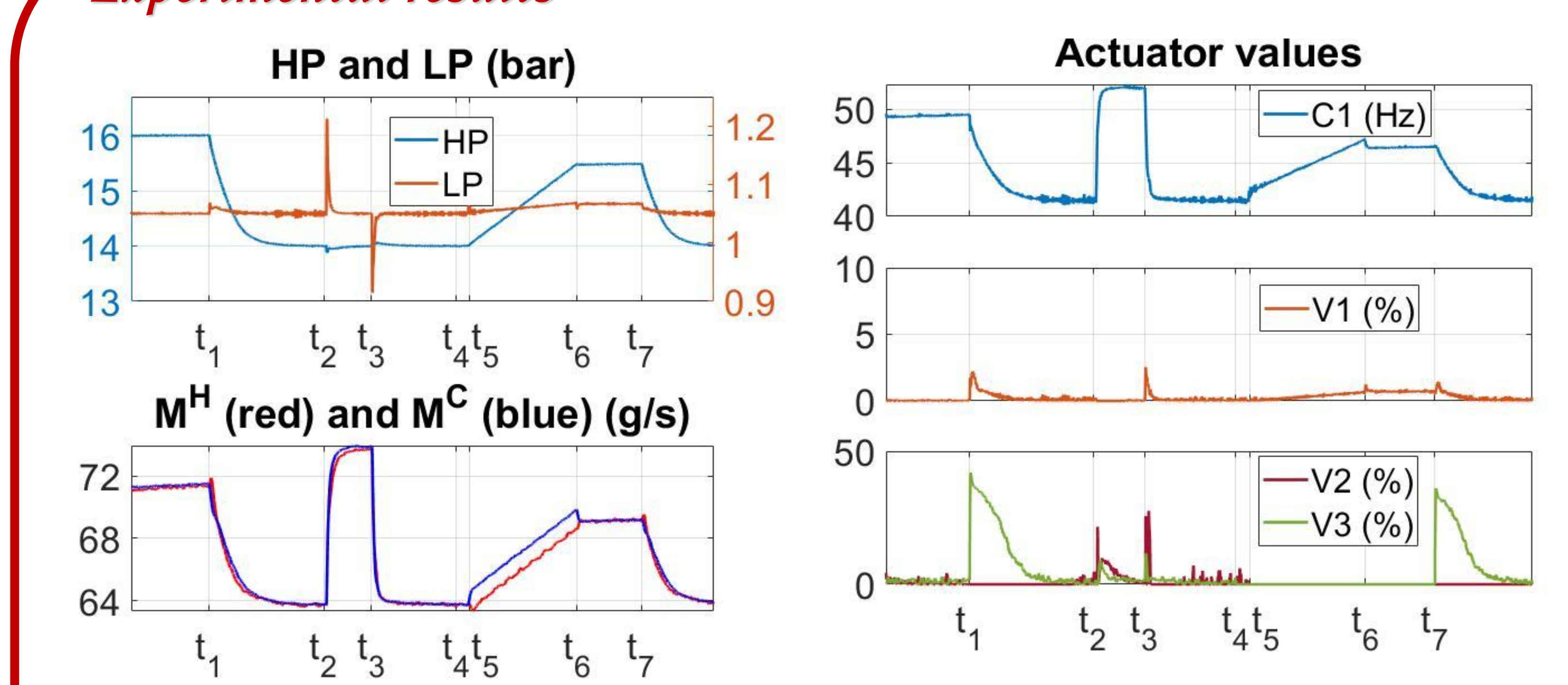


Figure 4: The control architecture is tested on the dSBT WCS with the scenario below

t_1: change HP set point to 14 bar → the high pressure follows the set point
t_2 to t_3 set offset V1 at 20 % → Controller rejects the disturbance (C1 speed inc.)
t_4: block V3 = 0 % with manual mode → the valve is blocked
t_5 to t_6: set offset V2 at 20% → HP increases due to the V3 being blocked at 0 %
t_7: release V3 from manual mode → the HP return to normal

Conclusion and future work

- The warm compression station of dST is controlled using MPC
- The MPC takes into account constraints on actuators (value and rate)
- The MPC allows to take actuators in manual mode
- In future work, the compressors maximum power will be taken as a constraint to avoid unexpected stop of the WCS due to compressor overload (by automatically lowering the set point for HP)