PROCESS CONTROL FOR PARALLEL RUN OF TWO HELIUM LIQUEFIERS AT VEC CENTRE, KOLKATA

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Abstract

Two helium liquefiers are working in tandem while one is always connected with the superconducting cyclotron at VECC. High pressure (HP) and low pressure (LP) controls are necessary to maintain varying helium flow to the cold box. Since these two liquefiers share the same HP and LP pipelines, any pressure fluctuation due to rapid change in flow sometimes causes trip of the liquefiers. To overcome this problem there is a need for fast responsive HP control. Introduction of derivative gain in the PID loop for fast action is not desirable as it creates instability to the control system. This problem was rectified by introducing a novel control scheme based on the forced opening of the unloading valve to push back helium gas to buffer tank by changing the offset of PI control as a function of Buffer Tank pressure. A simulation using Matlab Simulink was performed initially to check the performance of pressure control loop. The same is implemented in the control loop of the new liquefier and an experiment was performed. The experimental results obtained will be discussed in this paper.

INTRODUCTION

One helium liquefier is operational in VECC since 2001 [1]. The main application of this liquefier was to cater the cryoloads of the superconducting cyclotron in the form of superconducting magnet and cryopanels situated in main beam chamber for acceleration [2]. Another liquefier has been commissioned in VECC for redundancy purposes and for catering more refrigeration load [3]. Helium liquefiers are running in parallel – one running in refrigeration mode for the superconducting cyclotron and other running in liquefaction mode for supplying liquid helium to other users. The older liquefier cold box requires 50 g/s helium flow rate which is fed by either of the two cycle compressors of same capacity. The newly commissioned liquefier demands maximum 85 g/s flow rate of helium at refrigeration mode of operation. This requirement could be fulfilled either by a higher capacity compressor (85 g/s or above) or by two parallel connected compressors of lower capacity (50 g/s) as available earlier at VECC. In order to save expenditure, add reliability to the system and make use of the available compressors, a compressor of similar capacity was procured along with the new liquefier. For incorporating maximum flexibility to the cryogenic process, common warm pipelines are adopted and compressors are selected on *ad hoc* basis – one for old liquefier and two for new liquefier [4]. On the other hand, any flow instability, e.g. emergency stop of the compressor or cold box disconnection creates pressure fluctuation, that in turn causes trip of other liquefier. The trip of the liquefier connected with the cyclotron is totally undesirable as it results in uncontrolled release of pure helium gas from the cryostat and converts a significant amount of pure helium gas to impure form. A fast responsive control is necessary to cater these types of fluctuations. A newly adopted method is discussed here both with the simulation and experimental results.

SYSTEM DESCRIPTION

Figure 1 shows the cryogenic system of the super-conducting cyclotron, it has pure gas management system (buffer tanks and pure cylinder quad for low and high pressure storage respectively), Oil Removal System (ORS), pressure control loops, cold boxes of two liquefiers, helium storage Dewars, distribution box and cryoloads.

The gas management system consists of two control valves,

- one unloading valve which automatically sends excess helium inventory to the buffers when the helium gas generated is in excess compared to the refrigeration system capacity; and
- one loading valve which adds helium inventory to the system from the buffer tank when the liquefaction capacity is higher than the flow recovered from the cryomodules.

These two valves work in concert with the by-pass valve, which automatically recycles excess flow from compressor discharge to suction.

Pressure control loops play a significant role to maintain the compressor suction and delivery pressure (LP and HP respectively) so that the flow rate to one cold box is independent to the fluctuation of the other. The pressure variation from the set-point also degrades the liquefier performance.

There are few alarms in compressor and cold box control depending on the suction and delivery pressure. Each cold box is equipped with two turbo-expanders for isentropic expansion and subsequent cool down of helium gas. These turbo-expanders' operation is very sensitive to pressure, as high inlet wheel pressure, high delivery pressure, low bearing pressure, break pressure beyond safe limit may cause damage to the turbines. Therefore, every fluctuation in pressure causes stoppage of the turbo-expanders leading to the disconnection of the cold box.

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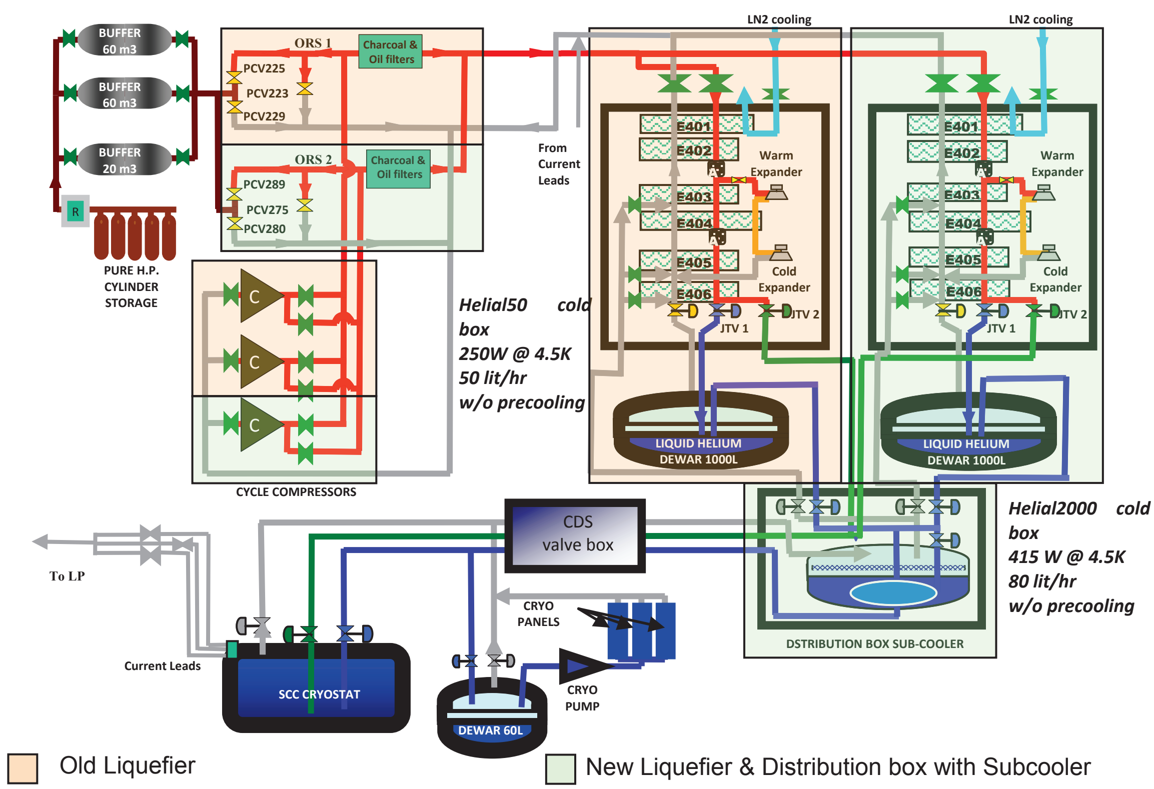

Figure 1: Schematic showing the cryogenic system consisting of buffer tanks, compressors, cold boxes, distribution boxes and cryogenic loads.

ROBUST PRESSURE CONTROL SYSTEM

To overcome pressure fluctuation problem there is a need for fast responsive HP control. This is only possible by adopting the derivative control in the PID (Proportional-Integral-Derivative) loop of HP control, but it generates pressure transients resulting in tripping of the turbo expanders. This problem was rectified by introducing a novel control scheme based on the forced opening of the unloading valve by changing the offset of Proportional-Integral (PI) control as a function of Buffer Tank pressure (BP). A better way is proposed by applying a linear shift on offset of the PI controller used for the opening of the unloading valve, i.e. HP to buffer, while HP is 2% more than setpoint. The more opening of that valve is proposed for the higher buffer tank pressure (BP) as per Equation (1), as the flow rate through a control valve is a function of the differential pressure between HP and BP as followed by Equation (2). It is also to be noted that valve opening is increased for lower value of offset.

$$Offset = (HP - BP) \times (Range) / (HP\_SP) \qquad (1)$$

where, *Range* is the maximum range of the opening of the control valve and *HP_SP* is the set point of the delivery pressure of the compressor.

Flow rate for compressible gas through a control valve

$$Q = C_v \cdot 2.80 \cdot \frac{\Delta x}{x} \cdot \sqrt{\frac{\Delta P(2P_1 - \Delta P)}{SG} \cdot \frac{273}{(273 + T_2)}} \qquad (2)$$

where, C_v is the flow coefficient of the control valve,
$\Delta x/x$ is the fractional opening of the control valve,
ΔP is the differential pressure across the control valve,
SG is the specific gravity of helium with respect to air at 20ºC and 1 atm,
T_2 is the downstream temperature of the control valve.

A simulation using Matlab Simulink has been performed initially to check the performance of pressure control loop. The same is implemented by two PI control loops - one for loading and unloading valves and other for the bypass valve. At start three compressors started together and after stabilization one of the compressors is stopped at 10000 s. The quantity of helium gas inside the compressor stopped is fed to the suction side creating an instant increase in LP pressure and decrease in HP pressure, as shown in Figure 3.

In Figure 3 normal PID control loops are used without the proposed modification. The pressure fluctuation in HP and LP is higher than the safe limit of compressor and cold box operation. Compressor suction pressure reaches to sub-atmospheric value and compressor delivery pressure jumps about ±3 bar from the HP setpoint.

Figure 4 shows the same simulation result with the modification of the control loops in which an instant opening of the unloading valve transfers excess amount of gas to the buffer tank. It reduces pressure fluctuations both in HP and LP and an increase in BP.

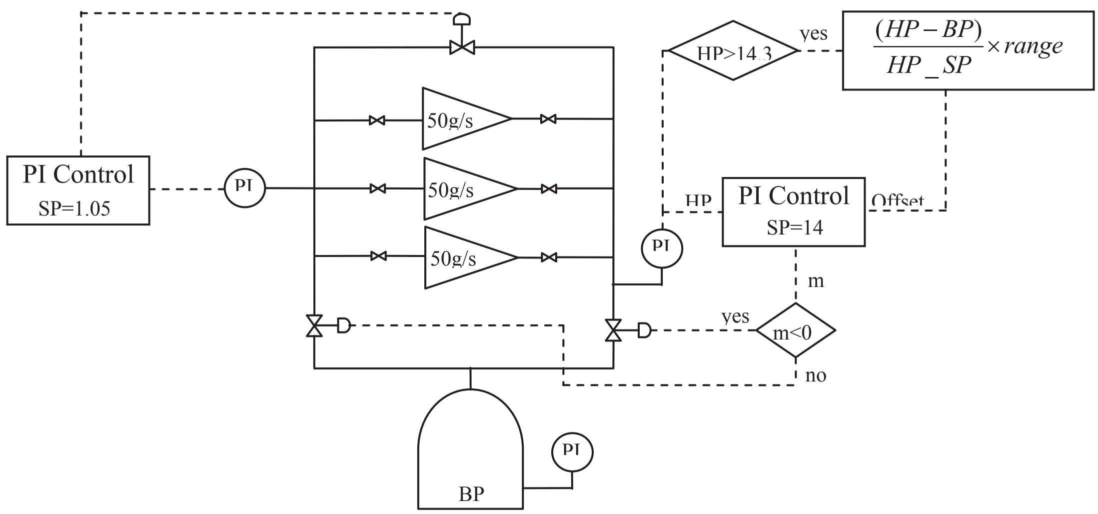

Figure 2: Pressure control of compressor suction and delivery for constant pressure operation of helium liquefier.

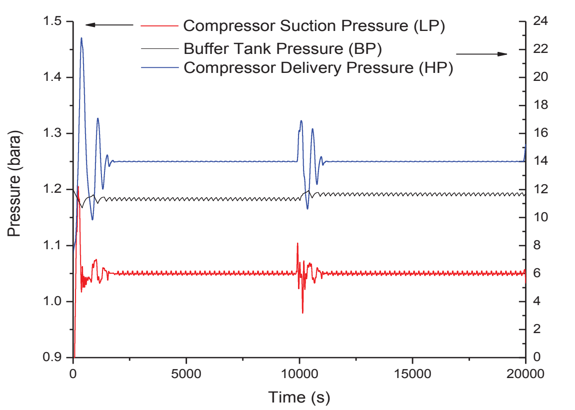

Figure 3: Simulation result (LP, HP and BP pressures) of warm helium process of the cryogenic system; only two normal PI loops are operational without any modification.

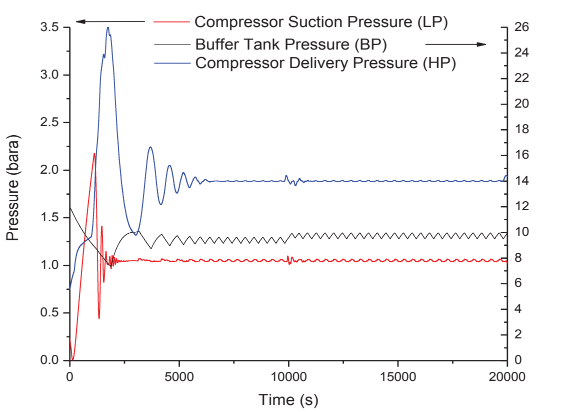

Figure 4: Simulation result (LP, HP and BP pressures) of warm helium process of the cryogenic system; with implementation of new unloading valve PID loop.

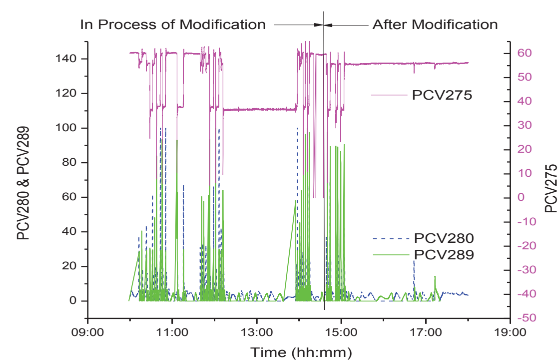

Figure 5: The fluctuation in opening of PCV289 to accommodate excess gas due to stopping of one compressor and that of PCV280 at the time of its start.

Figure 5 shows the fluctuation in opening of the loading and unloading valves (PCV 280 and PCV 289 respectively as shown in Figure 1 for Helial 2000) and bypass valve (PCV 275) before and after implementation of the new control scheme. The opening of PCV 289 is higher after modification because of the offset but the fluctuations in PCV 280 and PCV 275 get reduced after modification. Similarly, the fluctuations in HP and LP get reduced after implementation of new scheme as shown in Figure 6.

The same has been tried again by stopping the third compressor forcefully and displayed in Figure 7. Just after the compressor stopped, LP pressure increased and HP pressure decreased because of sudden flow rate reduction for the opening of the bypass valve. As the bypass valve took over the control and the suction side excess gas fed to the delivery side, LP pressure decreased and HP pressure increased to 14.3 bara. At that instant of time the unloading valve opened to some extent and it resulted in pushing the excess cycle helium gas from process to buffer tank. Ultimately, entire system stabilizes without causing any trip or alarm.

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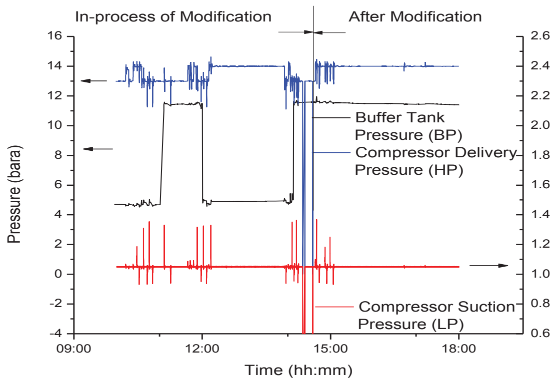

Figure 6: Buffer, LP and HP pressure curves before and after implementation of the proposed control scheme based on HP and buffer pressure.

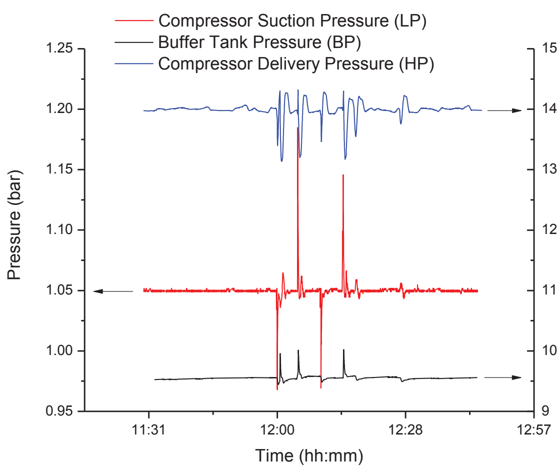

Figure 7: Buffer, LP and HP pressure curves at start and stop of a compressor with other two compressors running after implementation of the proposed control scheme.

CONCLUSION

This novel control scheme shows a way of smooth transfer of compressors in case of parallel run for liquefiers. This scheme has been running for more than two years without a single failure. Due to physical location of the running compressors, there is increase in pressure at the compressor outlet due to pressure drop in the process line between HP sensor and compressor delivery end. This problem may be subdued by proper setting of the compressor control. While a variable frequency drive (VFD) is put for flow rate control of the compressors, the new control scheme would be modified to take care of that situation. The VFD setpoint should be set in coordination with the bypass valve opening (in order to save electrical energy).

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