§13. Adaptation of Advanced Control to the Helium Liquefier with C-PREST

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The 300W class helium liquefier consists of two expansion turbines with a liquid-nitrogen precooler, seven heat exchangers, a liquid helium reservoir and a compressor. To investigate the dynamic behavior of the liquefier, the liquid helium reservoir is considered as a cryostat that provides variation of heat loads. Thus, the liquefier is designated as a helium refrigerator for this study.

To validate the adaptation of MATLAB® to the system, the feedforward control is implemented. The thermal disturbance to the system is introduced to the cryostat, assuming magnet quench and/or AC losses. It leads to the pressure build up in the cryostat as evaporating the liquid helium. As measuring the pressure fluctuation in the cryostat, the feedforward control is expected to stabilize the system operation. The modeling is based on the pressure variation in the cryostat as a disturbance and corresponding regulation of discharge pressure *PI2* by *ACV3A&B*; *ACV3A* is used to relief the discharge pressure as *PI2.PV>SV* and *ACV3B* is charging the helium gas as *PI2.PV<SV*. The fidelity of the modeling of P and P_d in the Figure are indispensable for successful control algorithm development.

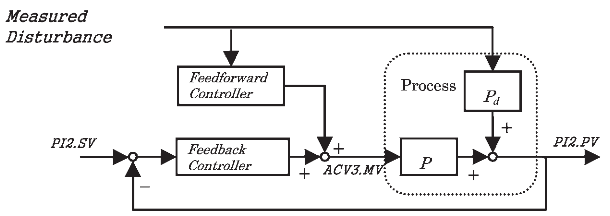

Fig. 1. Feedforward combined with feedback control structure.

It is well-known that the robustness of the system depends on the accuracy of the dynamic system modeling. Most general and flexible model is a Ready-made model, also known as a black-box model, which is the linear, discrete-time model as expressed as;

$$y(t) = G(q,\theta)u(t) + H(q,\theta)e(t) \qquad (1)$$

where *y(t)* is output, *u(t)* is input, $G(q,\theta)$ is transfer function $H(q,\theta)e(t)$ is disturbance term and θ is the parameter vector which contains the unknown system parameters.

Assume that the G is a rational function of the shift operator q;

$$G(q,\theta) = \frac{B(q)}{A(q)} = \frac{b_1 q^{-nk} + b_2 q^{-nk-1} + \cdots + b_{nb} q^{-nk-nb+1}}{1 + a_1 q^{-1} + \cdots + a_{na} q^{-na}} \qquad (2)$$

where b_i, a_i are coefficients of transfer function and *na*, *nb* and *nk* are structural parameters. q can be statistically determined from process Input/Output (I/O) signals with the least square method. Let $H(q)=1/A(q)$, then the equation (1) is expressed as;

$$A(q)y(t) = B(q)u(t) + e(t) \qquad (3)$$

This model is called an AutoRegressin with eXogenous variable (ARX) model .

To fit the parameterized models to the data, determining *y*, the minimization of prediction errors have to be conducted. As for ARX model, this minimization procedure is the same as the least square method. Two ARX models for P and P_d in Fig.1 have to be determined and its identification procedure is as follows.

Since the simulation model is already at hand, the accumulation of process I/O is being conducted by generating a collection of sinusoidal waves of different frequencies as excitation signal. The I/O signals were sampled with the frequency of 1 Hz as terminating any Proportional Integral (PI) control of the refrigerator. The data records contained 1000 points; the first half of records for system identification, the remained records for model validations. After cancelling a DC offset from the data records, let the data average equals to zero, the impulse response of the system are evaluated with correlation method. After manipulation of data records, ARX model was applied for the system identification of each process.

According to the obtained model for each process, equations (4) and (5), the model is stable to follow the essential change of output; fitting rate is 80 % for P and 90% for P_d.

$$P = \frac{5.65e^{-5} q}{q - 0.991} \qquad (4) \qquad\qquad P_d = \frac{0.164q}{q - 0.984} \qquad (5)$$

Fig. 2 shows a discharge pressure variation corresponds to the heat pulse to the reservoir. Feedforward control shows faster compensation against thermal disturbances than the feedback control.

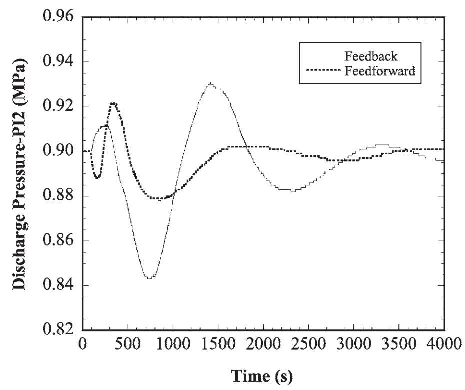

Fig. 2 Comparison of dynamic simulation results for the feedforward with feedback control.

A helium refrigerator model was utilized as a target plant to demonstrate and validate the system. According to the system identification and ARX modeling, the refrigerator was well controlled against the transient thermal disturbance in the cryostat. The computational speed of this project was approximately seven times faster than the real-time, which substantially reduced the time to assess different control parameters.