§11. Current Control for dc Power Supplies for LHD Magnets

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For the LHD superconducting magnets, high accuracy of current control is required to make good plasma confinement. This report introduces the coil current control system for the LHD. Figure 1 shows the structure of the computer control system for the power supplies. This control system has a hierarchy shown as the figure. The lowest level is a controllers in thyristor rectifier units. This unit has sensors, a local voltage regulation loop and small control sequencer. Next level is two VME bus computer systems. In these VME machines, the coil current regulator for magnetically coupled multi-coil system is installed. The highest level is an engineering work station. The VME machines and rectifiers are connected with serial line to transfer the current and voltage data.

For this control system, the required performances to the current regulator are as follows.

1. Control error in current regulator in steady state is less than 0.01%.
2. Settling time to the 0.1% of control error is less than 1 second for the normal operation.
3. No overshoot of current is available.

The current regulator in the VME machine is based on the state variable control theory to decouple the mutual coupling between coils. For the first cycle operation, the available machine time for debug and tuning of current control is only three days. Therefore following simple P and PI control scheme are selected and tested for the current regulator.

$$V^* = K_i(I_c^* - I_c)/s + K_p(I_c^* - I_c)$$

In the excitation of superconducting coils, passive currents flowing coupling structures like as a support shell may affect the current regulator. In the case of first cycle operation of LHD, time constants of passive circuits are less than 1 second and reactions caused by them are enough small because current lamp rate is small like as 10 A / s. Therefore magnetically coupled passive circuits are ignored in the design of regulator.

The resolution of A/D converter for coil current measurement is about 0.6A and it causes hunching of the output voltage when the feedback gain K_p is high. To reduce this hunching, a digital low pass filter is inserted in the regulator.The delay caused by this filter limits the maximum feedback gain.

With the consideration of voltage ripple and control error, the cut off frequency of filter and feedback gain are choice as 0.7Hz and 1.0.

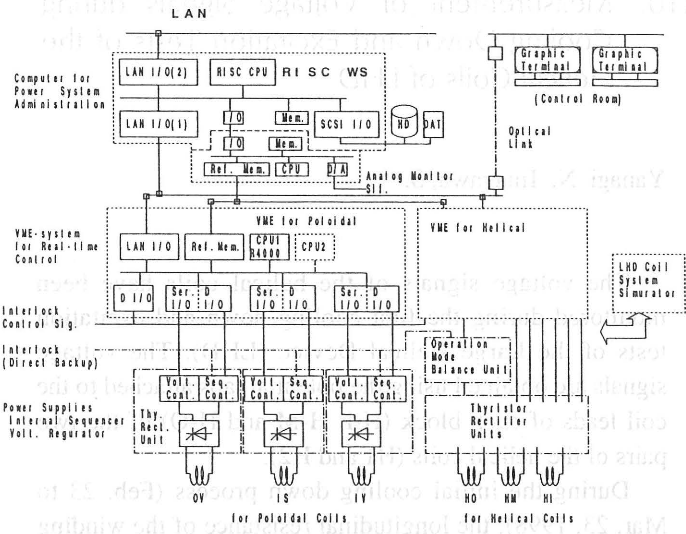

Fig. 1. Structure of Computer Control Sub-system for LHD Power supplies.

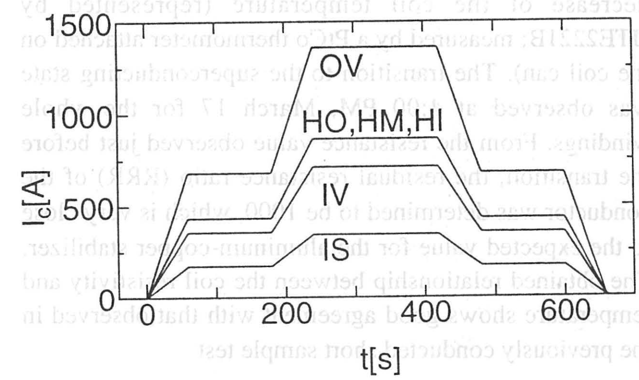

Fig. 2. Waveforms of LHD coil currents for 0.1 and 0.2 T operation.

As a result, current regulator is designed as follows,

$$\begin{bmatrix} I_f[n+1] \\ X[n+1] \end{bmatrix} = \begin{bmatrix} 0.9 & 0 \\ -dt & 1.0 \end{bmatrix} \cdot \begin{bmatrix} I_f[n] \\ X[n] \end{bmatrix} + \begin{bmatrix} 0 & 0.1 \\ dt & 0 \end{bmatrix} \cdot \begin{bmatrix} I_c^*[n] \\ I_c[n] \end{bmatrix}$$

$$V[n] = \begin{bmatrix} -K_p & K_i \end{bmatrix} \cdot \begin{bmatrix} I_f[n] \\ X[n] \end{bmatrix} + \begin{bmatrix} K_p & 0 \end{bmatrix} \cdot \begin{bmatrix} I_c^*[n] \\ I_c[n] \end{bmatrix}$$

where dt is the control period.

Figure 2 shows an example of waveforms of coil currents. With the experiments, it is confirmed that the current regulator realize decoupled current control with high accuracy.