Magnet Control System for the Two-arm Spectrometer System

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The new control system was designed and built for the operation of the two-arm spectrometers, Grand Raiden [1] and Large Acceptance Spectrometer [2]. The two-arm spectrometers consist of dipole, quadrupole, sextupole, and multipole magnets. Each of the magnets is powered by a Direct Current (DC) power supply independently. Remote control of the current settings for all the magnets is required to set the magnetic fields of the spectrometers which are located in the experimental room. High precision magnetometers based on Nuclear Magnetic Resonance (NMR) have been installed in all dipole magnets. Magnetic rigidities of the central rays of both spectrometers are determined by the magnetic dipole fields. DC currents of the dipole magnets have to be controlled precisely to generate the desired magnetic fields B by using the magnetometers.

High energy resolutions of ΔE=13.0±0.3 keV and 16.7±0.3 keV in full width at half maximum for 295 MeV and 392 MeV protons, respectively [3], have been achieved with the Grand Raiden spectrometer after employing dispersion matching. These energy resolutions agree with the design resolving power of Grand Raiden, $\Delta p/p = 2.7 \times 10^{-5}$, for an object size of about 1 mm. Thus the magnetic fields have to be stabilized within $\Delta B/B \leq \Delta p/p = 2.7 \times 10^{-5}$ in order to achieve the best energy resolution. Therefore a high precision feedback system is needed to satisfy this requirement. Furthermore, since magnetic fields of the spectrometers are frequently changed during an experiment, this feedback system could modify and stabilize the magnetic fields in particular of the large dipole magnets within a reasonably short time.

Figure 1 shows the new Graphical User Interface (GUI) for controlling the power supplies for the magnets of the spectrometers. The data entered in the fields for the preset currents are distributed either to the System Control Unit (SCU) [4, 5] or to one of the GPIB-Enet/100 modules [6] and the output currents of the corresponding power supplies are modified accordingly. The actual currents of the power supplies are monitored periodically and displayed in corresponding display fields. Green, yellow, and red colors of the "Status" indicators show the constant-current, transition, and disabled states of the outputs, respectively, whereas those of the "PS" indicators mean the online, offline, and off states of the power supplies.

The data of the magnetometers are displayed in the columns for the magnetic display fields. The "NMR" indicator shows whether the Nuclear Magnetic Resonance (NMR) signal is locked (green) or unlocked (yellow). The magnetometer reading of the NMR probe is displayed with the locked NMR signal, otherwise the Hall probe reading is shown.

The present control system was designed to provide feedback loops which allow to minimize the change and stabilization of the magnetic fields of the dipole magnets. We use a Proportional-Integral-Differential (PID) algorithm. In the PID feedback loop with the sampling time ΔT, the magnetic field setting F_n after the n-th sampling is given by

$$F_n = F_{n-1} + \left[-K_p(B_n - B_{n-1}) + \frac{\Delta T}{T_I}(B_\infty - B_n) - \frac{T_D}{\Delta T}(B_n - 2B_{n-1} + B_{n-2}) \right], \qquad (1)$$

where B_∞ is the object field value, B_i (i=1$\sim n$) is the measured field value in the i-th sampling, and K_p, T_I, and T_D are the parameters of the PID feedback loop corresponding to the

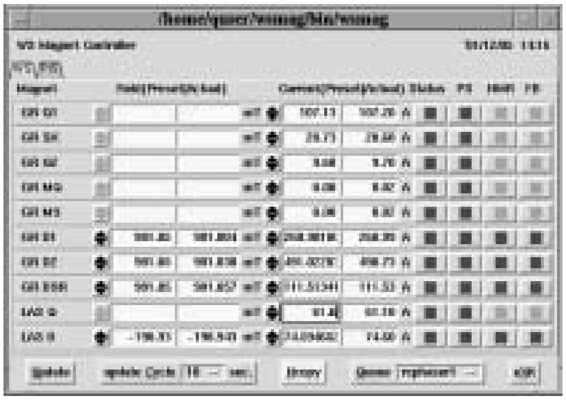

Figure 1: A view of the GUI for the spectrometer control.

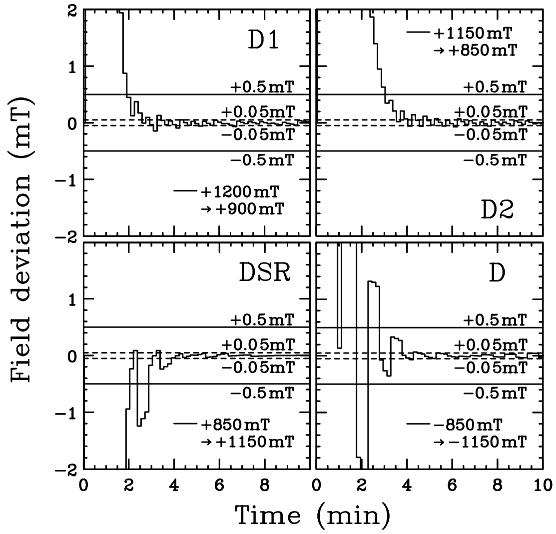

Figure 2: Typical magnetic field responses of the dipole magnets D1, D2, and DSR of Grand Raiden, and the magnet D1 of Large Acceptance Spectrometer.

proportional, integral, and differential components, respectively. The output current I_n of the power supply after the n-th sampling corresponds to the field F_n.

The values of the parameters K_p, T_I, and T_D depend on the response of the magnetic field, and they need to be optimized for each magnet. We require that the magnetic field should be changed and stabilized within ±0.05 mT of the preset value in less than 5 minutes. Furthermore the magnetic field should be stabilized within ±0.02 mT in less than 10 minutes. It was found that the differential term, the last term in Eq. (1), does not help to improve the response of the feedback system in our case. Therefore the K_p and T_I values are optimized with $T_D = 0$.

Figure 2 shows typical magnetic field responses of all four dipole magnets of the spectrometers as functions of time. The PID feedback system works very well and the magnetic fields are stabilized in 4–6 minutes within ±0.05 mT for all magnets. The magnet D2 of Grand Raiden takes the longest time of about 6 minutes because it is largest and its T_I value in Eq. (1) is larger than the others.

References

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