IMPROVING POWER SUPPLY PERFORMANCE FOR THE DUKE STORAGE RING *

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Abstract

As part of the recent Duke storage ring hardware upgrade (2001–2002), a power supply improvement program was put in place to bring all major DC supplies to their specifications. In carrying out this program, power supplies have been modified, tuned, and thoroughly tested. In its actual operation configuration, each power supply was subject to extensive testing to determine its DC stability, reproducibility and linearity, AC ripple and noise, and ramping performance. As a result, all major DC supplies have been improved to meet most important performance specifications for 1 GeV operation.

1 INTRODUCTION

The Duke storage ring and its main light source, the OK4 free electron laser (FEL), were commissioned in 1994 [1] and 1996 respectively. Since 1998, the Duke FEL storage ring has been operated for FEL research in the UV and deep UV region for a variety of user applications in medicine, biophysics, solid state, and nuclear physics. However, prior to the 2001 upgrade, the Duke storage ring suffered from a number of hardware problems, resulting in frequent machine down-times and beam dropouts. A major contributor to these problems was the unreliable performance of the DC power supplies. All ring quadrupoles were powered individually by small DC supplies which did not meet specifications for a modern storage ring. The second problem was a quad coil overheating problem at high energy operation ($E > 750$ MeV). To address these problems, the following upgrades were carried out during an upgrade shutdown (2001-2002): (1) all arc quad coils were replaced with specially designed new coils with inline water cooling; (2) small arc quad supplies were replaced with higher performance supplies which fed families of arc quads in series; (3) straight section quad supplies were replaced by new supplies with better performance; (4) all major supplies were tested and tuned. In this paper, we first present the performance specifications for the main DC supplies. We then report power supply modifications carried out in order to achieve these specifications. Finally, we present the measured power supply performance including DC stability, reproducibly and linearity, AC ripple and noise, and ramping characteristics.

2 SPECIFICATIONS AND MODIFICATIONS

Three different types of DC power supplies are used to drive the main magnets in the Duke ring. Forty (40) ring dipoles are fed in series by a PEI supply in use since 1993 (PEI SR1074, 800V/700A). Two families of thirty-four (34) combined function quad-sextupoles in the arc are driven in series by four (4) new supplies (Bruker B-MN, 60V/833A) from Bruker Analytische Messtechnic GmbH in Germany. The end-of-arc and straight section quads are powered in series or individually by eighteen (18) new supplies (Walker HS-7040-4SS, 70V/40A and 50V/40A after modifications) from Walker Scientific, Inc. in US.

2.1 Performance Specifications

The specifications for these supplies are determined by beam stability requirements, in particular, the amount of tune variations allowed. The desirable maximum tune variation should not exceed that of the tune spread of the beam. The following beam parameters are assumed for nominal operation: (1) energy = 1 GeV; (2) horizontal and vertical chromaticities, $\xi_x = 1.3$, $\xi_y = 2.6$. The allowed tune variations are (RMS) $\nu_x = 0.75 \times 10^{-3}$ and $\nu_y = 1.5 \times 10^{-3}$ respectively. This translates to the following rather conservative power supply specifications:

- Dipole PS (PEI): $\frac{\Delta B}{B} \leq \pm 25$ ppm;
- Arc quads PS (Bruker): $\frac{\Delta K_1}{K_1} \leq \pm 25$ ppm;
- Straight section quad PS (Walker): $\frac{\Delta K_1}{K_1} \leq \pm 50$ ppm.

$d\nu_x$, $d\nu_y$ [10^{-3}]	**Dipoles**	**Arc Quads**	**SS Quads**	**Total**	**Tune budget**
DC, X	0.250	0.085	0.125	0.292	0.750
DC, Y	0.250	0.145	0.225	0.366	1.500
AC, X	0.250	0.170	0.400	0.820	0.750
AC, Y	0.250	0.290	0.700	1.240	1.500

Table 1: Allowed RMS tune variations for main supplies.

The allowed tune variations for various supplies are listed in Table 1. The tune drift (DC) caused by each supply is assumed to be uncorrelated. The total tune drift is calculated as the root of the quadratic sum of contributions from all supplies. For the AC performance, the tune jitter is assumed to be dominated by line-frequency related ripples. The total tune jitter is then calculated as the sum of all contributions. The Duke ring is operated with a wide energy range from 270 MeV to 1.2 GeV. Whenever possible, we strive to achieve the same level of power supply performance for all energies.

2.2 Power Supply Modifications

A number of modifications were made to the PEI, Bruker, and Walker supplies during the upgrade to achieve the desirable performance. The PEI dipole supply had been in operation since 1993. However, its ripple, noise, and

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ramping performance were not satisfactory. The PEI performance was improved with the following modifications: (1) active damping was developed to suppress the resonance of the LC filter; (2) the firing circuit was adjusted for 60 Hz reduction; (3) the filter inductor was rearranged to suppress common-mode noise. In addition, the current regulator was modified to match the load impedance for overshoot reduction.

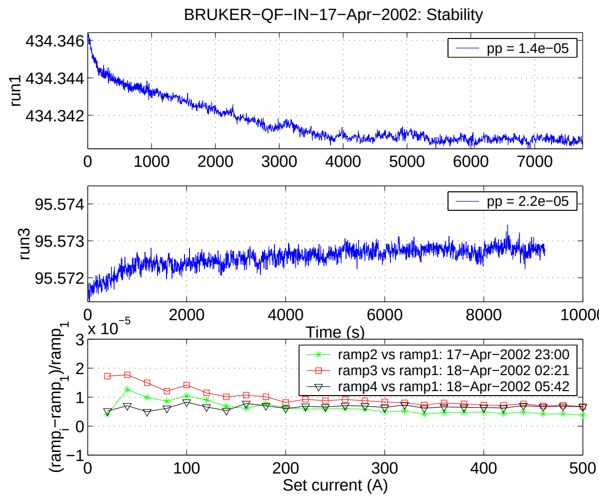

Figure 1: Stability and reproducibility for Bruker powering QF inner coils.

The new supplies had their share of problems. All of the five newly acquired Brukers were out of absolute calibration by about 1% and one had a large zero offset. These problems were corrected on site by a Bruker technician.

The most extensive modifications were made to the Walker supplies. First, the Walker transformers had to be reconfigured to match different loads. The load variation was the result of driving either two or four quads coils and of variations in output cable length. Second, the digital control (RS-232C) was found to be too slow for our ramping requirements and the internal ADC readback too inaccurate. All supplies were then retrofitted to provide differential analog control and readback. Third, the remote/local control did not work properly and had to be replaced. Fourth, the long-term (24–48 hours) stability was found inadequate because the current regulation shunt had a relatively large temperature coefficient. To overcome this problem, the shunt temperature was stabilized using a stand-alone water cooling system.

3 DC PERFORMANCE

DC measurements are performed to determine the stability, reproducibility, and linearity for each power supply. All DC measurements are completed in a single run using a test protocol which interleaves stability tests with slow-ramp tests. The stability tests cover several energies from injection to 1.2 GeV; the ramp tests takes the supply from its minimum to maximum operation current. The DC stability is calculated as the peak-to-peak (P-P) current variation. The linearity, more precisely the deviation from linearity, is computed as the difference between the readback and its linear fit. The reproducibility is calculated from the slow-ramp runs as the difference current for the same control setting.

A Danfysik current transducer was used for measuring DC currents for PEI and Brukers (Danfysik 860R, 2kA) and for Walkers (Danfysik 866, 600A). The Brukers were controlled digitally; the PEI and Walkers were controlled by 20-bit and 16-bit DACs, respectively. The output voltage from the transducer was recorded by a HP 3458A digital multimeter.

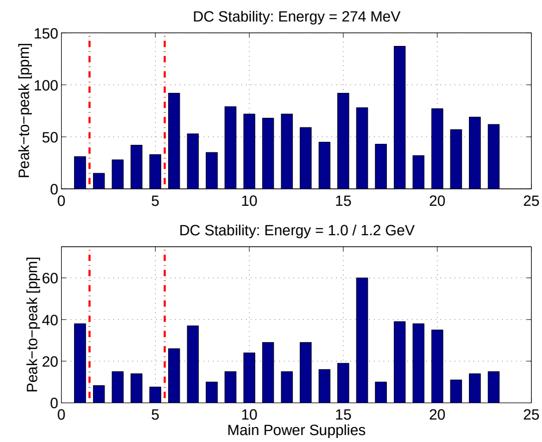

Figure 2: Main power supply DC stability. The first supply is PEI, followed by 4 Bruker and 18 Walker supplies. The test duration is typically 3 hours. The peak-to-peak variations are computed after dropping the first 10% of data.

Fig. 1 shows the DC performance of a Bruker supply powering the inner coils of the arc QF family. For all four Brukers, the P-P current variation (stability) is less than 50 ppm for energies from 270 MeV to 1.2 GeV. The reproducibility of all Brukers is less than 55 ppm for the entire energy range. The deviation from linearity is typically 100 to 150 ppm at 270 MeV settings and less than 50 ppm at 1 GeV. A relatively large deviation from the linear control is the result of using the 16-bit coarse DAC in the test. Due to the lack of integrated control of the internal coarse and fine DACs, only the coarse DAC was used for Bruker control.

The stability results for all major DC power supplies are shown in Fig.2 for two ring energies. With the exception of two Walkers, all supplies satisfy the stability and reproducibility specifications from injection (270 MeV) to full energy of 1.2 GeV. The linearity is a less critical performance requirement. All supplies are within a factor of three of the linearity specifications.

4 RIPPLE AND NOISE PERFORMANCE

AC ripple and noise measurements were performed at a number of DC current settings. The measurement system consists of a current transducer, a voltage amplifier with a built-in filter (1Hz - 3 kHz), and a LeCroy digital scope. The measured data were analyzed for line related ripples

(60 Hz, 120 Hz, etc.) and noise. To evaluate the overall AC performance of various supplies, a simple merit was chosen as the RMS variation of the current.

The overall ripple and noise performance for all major supplies is shown in Fig. 3. At the full energy (1.0-1.2 GeV), the AC performance of all supplies is within the specifications. At the injection energy, while all Walkers are still within the specifications, PEI and three Brukers are out of specifications. Since we have set a very conservative spec for the AC performance, it is expected that the amount of tune jitter at the injection energy is still quite acceptable.

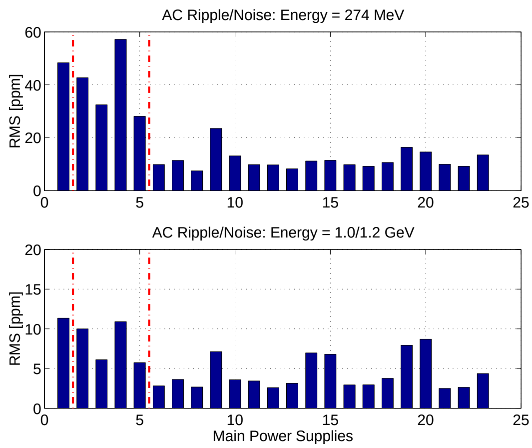

Figure 3: Main power supply AC ripple and noise performance. The first supply is PEI, followed by 4 Bruker and 18 Walker supplies.

5 RAMPING PERFORMANCE

Besides the DC and AC performance, the dynamic performance of the power supply is critical for reliable operation with energy ramping. Two important ramping parameters are the current overshoot and time constant for stepping control. These parameters determine the beam stability during ramping, the field reproducibility after ramping, and ultimately the total ramp time for reliable operation with energy ramping.

With digital control, the Brukers were found with satisfactory ramping performance after a simple adjustment of the internal slew rate. The Walker supplies were found to be relatively fast, with a time constants around 70 msec. However, significant overshoot were found at a 20% to 30% level. One test Walker supply was modified to demonstrate that the overshoot could be effectively suppressed with proper tuning. The rest of the Walkers remain to be tuned.

The reliability of energy ramping depends heavily on the performance of the dipole supply PEI. The PEI supply had been modified extensively in order to reduce the overshoot. Fig. 4 shows the measured step responses of the PEI output current before and after the modification. Before the modification, the current overshoot is about 50% of the step size. After the modification, the large overshoot is essentially eliminated and the time constant for stepping is 0.15 sec. This time constant is a good match with the ramping rate of the control system at 5 Hz [2].

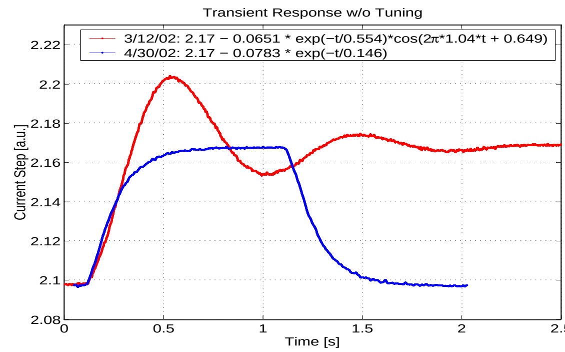

Figure 4: PEI dynamic response to stepping control voltages. A large overshoot was observed before tuning and was completely suppressed after tuning.

6 CONCLUSION

After modifications and tuning, all major supplies for dipoles and quadrupoles are found to have reasonable DC and AC performance at the high energy (1.0-1.2 GeV) in terms of stability, reproducibility, linearity, noise, and ripple. The AC noise performance of PEI and Brukers at the injection energy (270 MeV) needs further improvement. The dynamic performance of Walkers is not satisfactory; each Walker needs to be tuned to match its actual load in order to suppress the overshoot and achieve the same time constant. The overall performance of these DC supplies has been found to be rather adequate during past one-year operation. To sustain this level of performance, an active performance monitoring program [3] has been put in place to uncover emerging power supply problems.

With our power supply improvement program, we have learned several valuable lessons. First, very detailed and well thought-out specifications are critical in selecting an appropriate supply for a particular operation. This process will eliminate many unnecessary on-site modifications after delivery which can be time consuming and expensive. Second, one should expect that even a good supply will need some modifications and tuning in order to satisfy all performance requirements. Third, a thorough testing program with power supplies connected to their actual loads is essential to uncover problems for further modifications and to obtain actual performance of supplies under realistic operation conditions.

7 REFERENCES

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