MAGNET POWER SUPPLIES OF PLS 2 GeV STORAGE RING *

Sang H. Nam, Seong H. Jeong, Sung H. Han, Jae H. Suh, Ki M. Ha, and Moohyun Yoon
PAL, POSTECH, Pohang, Korea

Abstract

Total 215 magnet power supplies are under operation in Pohang Light Source (PLS). Current, voltage, and peak power handling capabilities of DC power supply are in the range of 21 to 643 volt, 45 to 850 A, and 0.94 to 531 kW, respectively. The DC supplies can be categorized as uni-polar and bipolar power. Typical required stability and ripple of uni-polar power supplies are ±0.005% and ±0.05%, respectively. The bipolar power supplies should be maintained within ±0.05% stability and ±0.5% ripple. Precise measurement results show that all power supplies meet or exceed the required specifications. The long term operation reliability and stability of the magnet power supplies are appeared to be sufficient for a stable operation of the Pohang Light Source.

1 INTODUCTION

The Pohang Light Source (PLS) is a 2 GeV third generation synchrotron radiation facility that has a 2 GeV full energy injection linac and a 280 m circumference storage ring. Construction of the PLS began in April 1988 and completed in September 1994. Since the beginning of the project, Pohang Accelerator Laboratory (PAL) staff had started to develop high precision magnet power supplies in house [1]. The storage ring magnet power supplies were designed to operate stably over the 2.5 GeV full energy range of the ring. Power supply specifications were provided by the PLS beam physics group based on allowable tune shifts and the beam stability requirements of the storage ring. The development was very successful and operation of the PLS could be started as scheduled without much difficulties. After the installation of all magnet power supplies in the storage ring of PLS, they passed the first commissioning period from September 1994 to December 1994. The second commissioning was performed during April 1995 to July 1995. The goal of the second commissioning was to provide stable and good quality beam with least 10 hour lifetime to users of PLS. During the second commissioning, the magnet power supplies showed very good and reliable operation performance. The goal of the second commissioning was achieved on July 1995. After the second commissioning, we started to provide beams to users from September 1995. Since then, the magnet power supplies have been in 24 hour continuous operation except the scheduled time of regular shut-down.

There are total 215 magnet power supplies are under operation in PLS storage ring. In the table 1, a list of magnet power supplies installed in the PLS storage ring is given. As shown in the table, the power supplies can be catagorized as unipolar power supplies and bipolar power supplies. Unipolar power supplies are for bending, quadrupole, sextupole, and septum magnets. Bipolar power supplies are for vertical and horizontal corrector magnets. All these power supplies have accumulated operation time of more than 8000 hours since the beginning of PLS operation.

Table: 1 Specifications of Magnet Power Supply

		DC Output		Ripple	Stability	Linearity
MPS	No	I [A]	V [V]	ΔI/Imax (%)		
BD	1	850	643	± 0.05	± 0.005	± 0.02
Q1	12	137.32	83.9	± 0.05	± 0.005	± 0.02
Q2	12	137.32	133.5	± 0.05	± 0.005	± 0.02
Q3	12	137.32	101.4	± 0.05	± 0.005	± 0.02
Q4	1	600	326.2	± 0.05	± 0.005	± 0.02
Q5	1	600	421.7	± 0.05	± 0.005	± 0.02
Q6	1	600	268	± 0.05	± 0.005	± 0.02
SF	1	198	179.8	± 0.5	± 0.05	± 0.2
SD	1	198	179.8	± 0.5	± 0.05	± 0.2
SQ	4	± 17	± 55.5	± 0.5	± 0.05	± 0.2
CH	70	± 45	± 21.0	± 0.5	± 0.05	± 0.2
CV	70	± 110	± 21.0	± 0.5	± 0.05	± 0.2
SCH	12	± 16	± 55.5	± 0.5	± 0.05	± 0.2
SCV	12	± 13	± 55.5	± 0.5	± 0.05	± 0.2
BT	4	± 10	± 31.1	± 0.5	± 0.05	± 0.2
ST	1	200	49	± 0.5	± 0.05	± 0.1

BD: Bending, Unipolar Q#: Quadrupoles, Unipolar
SF, SD: Sextupole, Unipolar SQ: Skew quadrupole, Bipolar
CH, CV: Horizontal and vertical corrector, Bipolar
SCH, SCV: Sextupole horizontal and vertical corrector, Bipolar
BT: Bending trim, Bipolar ST: Septum, Unipolar

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2.1 Power Supply Parameter Measurement

Various operation parameters of magnet power supplies are measured during 2.0 GeV operation. For the measurement of DC output currents, high precision DCCTs and a precision digital multi-meter are used. The DCCTs are zero flux current transducers (Holec 1000SH, Holec 300SEP, and DANFYSIK 860R). All have better specifications than a 5 ppm linearity error, a 1ppm/°K temperature coefficient, and a 10 kHz bandwidth. The precision multi-meter (HP 3458A) has a 8 1/2 digits resolution, and a 0.6 ppm 24-hour accuracy. For the DC output voltage measurement, a 10:1 Tek voltage probe and a digital multi-meter (Fluke 8505A) are used. The voltage measurement has better accuracy than 20 ppm. The DC current and voltage are acquired simultaneously. In addition to the DC output monitoring, AC input parameters are also acquired. For the AC measurement, a three phase power analyzer (PM3300) is used which has a ± 0.05% reading accuracy. Configuration of transformers for each power supplies are quite different. Therefore, AC parameters of transformer primary as well as secondary are seperately measured. In Table 2, the measured DC parameters are summarized. The data shown in the table are collected over a 24 hour period with a 2.5 second acquisition time step. From a comparison of the tables 1 and 2, the measured RMS current stability is generally smaller than the required. The voltage is also very stabilized. The voltage result directly corresponds to the load stability because the load variation is calculated from the measured data of current and voltage. The load stability indirectly implies that the magnets in the storage ring are under a very well controlled environment. In general, there are an order of difference in measurement data between peak-to-peak and RMS stabilities. Measured data of the AC line voltage and current show that the variations are in the range of ± 0.5 to ± 1.7 % and ± 0.4 to ± 7.6 %, respectively. The stable AC line is because of an independent power line that is directly coming from a power plant to the PLS power station. Measured linearity of the bending magnet power supply is ± 0.08% which is not within the required linearity of ± 0.02%. More investigation and improvement on the linearity are planned in near future. Spectrum of the magnet power supply output current are also measured during 2.0 GeV storage ring operation in order to correlate with a beam instability. The results are summarized in Table 3. In the table, resonance frequencies calculated from the power supply LC filter, spectrum frequencies corresponding to the resonance, amplitudes, and operating DC currents are also listed. As can be seen from the table, the measured frequencies are directly corelated to the LC filter resonance frequencies. During the storage ring operation, we recognize that there is a low frequency oscillation in the stored beam that has a frequency range of tens of hertz. More investigation will be continued whether the power supply oscillation is affecting the stored beam. Ripple components of each power supplies are also measured by using a DCCT and a high bandwidth oscilloscope. RMS values of ripple componets can not be measured with this methode because of the poorly definable ripple frequencies. However, approximate RMS ripple is well within the required value. A sample of the quadrupole magnet power supply (Q3) ripple is shown in Figure 1. The oscillogram has a 73 mA per a vertical division. One vertical division is, in other words, 532 ppm for Q3. As given in the table 1, the required ripple allowance of Q3 is ±500 ppm (or ±0.05%) rms. Therefore, the acceptable range in the oscillogram is about two division. From the figure 1, one can therefore

Table: 2 Measured DC Parameters of Power Supply

	Current Stability		Voltage Variation		Load Variation	
	p-p	RMS	p-p	RMS	p-p	RMS
BD	175.2	±23.9	700.7	± 87.9	745.2	± 92.2
Q4	53.0	± 6.0	801.1	± 88.9	777.5	± 88.9
Q5	245.5	±19.1	827.9	±108.8	787.0	±104.5
Q6	258.0	±29.3	2,961.2	±231.4	2,907.5	±232.4
SF	123.3	±13.3	2,448.6	±180.1	2,468.1	±180.7
Q1	197.6	±24.3	1,252.3	±112.1	1,254.4	±112.7
Q2	80.99	±9.4	691.0	±89.2	699.7	±91.8
Q3	90.9	± 9.0	541.1	± 66.6	559.5	± 67.1
CH	513.9	±72.9	--	--	--	--
CV	55.4	±10.5	--	--	--	--

p-p: Peak to peak value in ppm (parts per millon)
RMS: Standard deviation value in ppm

Table: 3 Ripple Content of Magnet Power Supply

	C Freq.[Hz]	M Freq.[Hz]	R Irms[mA]	DC I [A]
BEND	9.65	9.812	3.23	662.25
Q1	12.5	12	0.74	35.432
Q2	12.5	11.188	0.39	83.343
Q3	12.5	11.562	0.52	95.7425
Q4	14.35	13.812	5.5	339.61
Q5	8.3	7.625	3.5	415.56
Q6	12.12	10.125	31.26	186.025
SF	14.5	13.25	3.28	107.1

C Freq.: Calculated oscillation frequency
M Freq.: Measured oscillation frequency
R Irms: RMS ripple current amplitude at the oscillation
DC I: Operating DC current

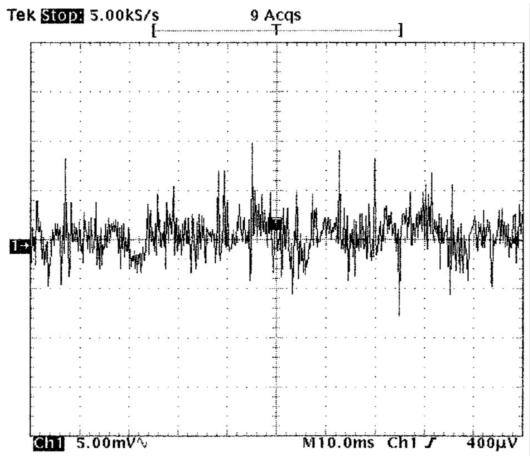

Figure: 1 Ripple oscillogram of a quadrupole magnet power supply, Q3. (73 mA/Div. or 532 ppm/Div., 10 ms/Div.)

easily understand that the rms ripple is less than the required rms ripple of ±500 ppm. AC parameters of the rectifier transformer primaries are also recorded. Measured power factors are in the range between 0.3 and 0.9. The power factor depends on a firing angle of SCR (i.e., a ratio of maximum to operating current) and also an existence of power correction circuit. Total current harmonic distortion varies from transformer to transformer, and the range is in 5 to 70 %. The variation also depends mainly on firing angles and power factor correction capacitors. Total voltage harmonic distortion of all transformers is also measured and the values are all less than 2 %. During 2 GeV operation, total real power consumed by magnet power supplies is 720.32 kW which is about 19% of total power needed during the operation. Overall efficiencies of the magnet power supplies are calculated from the recorded data and they are generally above 80 %. The 20 % power loss term is mainly due to rectifier transformers, SCR switching devices, and long length cables used for power supply connections.

2.2 Energy Ramping

Full injection energy from the PLS linac is 2.0 GeV. Accordingly, the storage ring operation energy is also 2.0 GeV. However, a need to operate the storage ring with 2.5 GeV energy arises recently. Thus, the energy ramping is tried by carefully synchronizing relative current incrases of the magnet power supplies. We are able to reach 2.5 GeV beam energy from the trial. A 0.01 % energy increase step from 2.0 GeV to 2.5 GeV is acceptable during the energy ramping without deforming the stored beam. Total time to reach the desired energy is about 15 minutes. All magnet power supplies perform satisfactorily during the energy ramping. Continuous monitoring of power supply stability and reliability is planned so that long hour stable operation at 2.5 GeV can be realized from the year of 1997.

2.3 Failure

During the storage ring operation, the magnet power supplies malfunctions once in a while. Most of the failures are at low level controllers and communication circuits that can be easily affected by external switching noises. In some cases, internal protection interlocks show problems. However, no single failure of the power devices such as transformers and SCR switching devices is observed so far. In Figure 2, a bar graph is shown. The graph illustrates machine failure statistics that were collected during a operation period from September to December 1995 [2]. In general, beam availability of the PLS to users is above 95 % of the scheduled operation time. The graph in the figure 2 is only reflecting collected failure data of machine parts excluding vacuum components. The magnet power supply failure among the storage ring machine components was 23.5 % during the period as shown in the figure. The failure occurances of magnet power supplies are however gradually reducing as the operation experience grows.

3 CONCLUSION

There are total 215 magnet power supplies are under operation in the storage ring of the PLS. Various power supply parameters are measured recently. The measurement shows that all power supplies meet or exceed the required specifications except the power supply linearity. Required stability and ripple of unipolar power supplies are typically ±0.005% and ±0.05%, respectively. The bipolar power supplies have ±0.05% stability and ±0.5% ripple requirements. Since the end of construction in September 1994, the magnet power supplies have generally shown satisfactory performance. Failure rates of the power supplies are gradually reducing as the operation experience of the PLS accumulates.

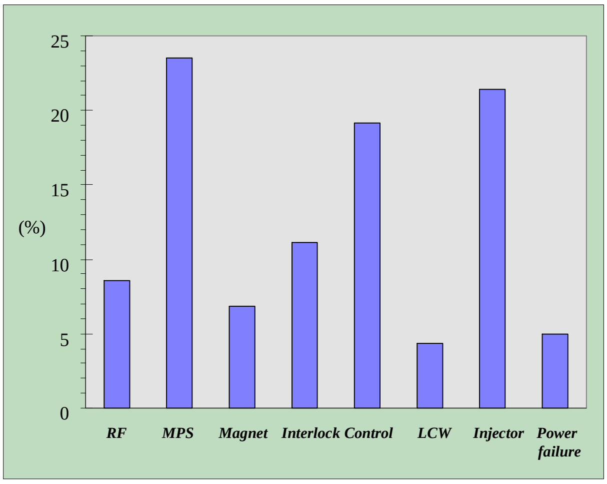

Figure: 2 Failure statistic of PLS storage ring devices during 1995 operation.

REFERENCES

[1] B.H. Kwon, E.H. Song, "Design of Current Source using 12-Pulse Phase-Controlled Rectifier," IEE Proc.-B, 138, 4, July 1991.

[2] 1995 PAL Annual Report, Pohang Accelerator Laboratory, 1995.

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