# A HIGH CURRENT SHUNT REGULATOR FOR QUADRUPOLE MAGNETS IN PLS 2GeV STORAGE RING

S.H. Nam, J. H. Suh, K. M. Ha, J. Y. Huang, and I. S. Ko
Pohang Accelerator Laboratory, POSTECH, Pohang 790-784, Korea

*Abstract*

Total 144 quadrupole magnets are installed in the PLS. The magnets are connected in series with groups of two or 24. Each group is powered by a high-precision constant-current DC power supply. For the purpose of the beam based alignment of beam position monitors in the PLS, it is necessary to adjust the current of each quadrupole independently. To achieve this, a high current shunt regulator is designed. It can shunt a maximum 50 A of the quadrupole magnet current. The shunt regulator is programmable and the current amplitude can be varied linearly with a 12-bit resolution. Power transistors are used in the current shunt regulator. The operation of transistors is in linear region. The RS232C protocol is used for remote control and status report of the shunt regulator to the main control centre of the PLS. Preliminary result indicates that the calibration accuracy of the beam position monitor can be achievable in less than 10μm.

## 1 INTRODUCTION

In an electron storage ring, the luminosity and performances of stored beam are mainly determined by precise alignment of quadrupole magnets. The stored beam is designed to pass through the centre of quadrupole magnets. Even though quadrupole magnets of the PLS storage ring are carefully aligned, there still exists residual offsets between beam position monitors (BPM) and the magnetic centre of the quadrupole magnets. To measure and correct this offset, a method of the beam based alignment (BBA) is commonly used [1]. However, in the PLS storage ring, quadrupole magnets are grouped by two or 24 and connected in series to their power supplies. So the individual control of each quadrupole magnet current is not possible. By introducing a high current transistor shunt regulator, the individual control of magnet current for BBA is successfully achieved.

## 2 PLS QUADRUPOLE MAGNET

Quadrupole magnets in the PLS storage ring are categorised in 6 different types: Q1, Q2, Q3, Q4, Q5, and Q6. The PLS storage ring consists of 12 superperiods, and two magnets of each quadrupole type are installed in a superperiod. Hence, there are total 144 quadrupole magnets in the storage ring. For Q1, Q2, and Q3 magnets, two magnets in each superperiod are grouped together. For Q4, Q5, and Q6 magnets, all 24 magnets are grouped. Each group is connected in series and powered by single power supply. Therefore, total number of power supplies for quadrupole magnets is 39. Since the quadrupole magnets are connected in series in groups of two or 24, the current of individual magnet is not controllable. However, individual control of the quadrupole magnet current is required for the BBA operation. In Table 1, important characteristics of quadrupole magnets are listed. A resistance of magnet is given in a column of ***R***, and a maximum output voltage of magnet power supply is given in a ***V Max.*** column. Current (I) and voltage drop (V Drop) in Table 1 are values for a 2 GeV operation.

Table 1: Characteristics of PLS Quadrupole Magnets

| Mag -net | Qty. | R [Ω] | V Max. [V] | I [A] | V Drop [V] |
|---|---|---|---|---|---|
| Q1 | 24 | 0.257 | 83.9 | 35.5 | 9.10 |
| Q2 | 24 | 0.429 | 133.5 | 83.4 | 35.76 |
| Q3 | 24 | 0.318 | 101.4 | 95.85 | 30.43 |
| Q4 | 24 | 0.021 | 326.2 | 339.7 | 6.97 |
| Q5 | 24 | 0.027 | 421.7 | 415.7 | 11.16 |
| Q6 | 24 | 0.016 | 268.0 | 186.0 | 3.05 |

## 3 SHUNT REGULATOR

### *3.1 Design Approach*

A shunt regulator is typically connected in parallel with a magnet to shunt a desired current while maintaining the neighbouring magnet current constant. Important design requirements of the current shunt regulator are following: The regulator

- shunts 5 to 10 % of magnet current,
- should be able to adjust each quadrupole current independently,
- has a remote control capability,
- maintains stability (<±0.005%) and ripple (<±0.05%) of magnet main current while operating the shunt,
- should not kill the stored beam from turn on and off transients.

As listed in Table 1, the magnet current varies from 36 A to 416 A. We select two types of the shunt. They are 15 and 50 ampere shunts that can commonly accommodate the required shunt current. The 15 A shunt is for Q1, Q2, and Q3 quadrupoles. The 15 A unit is also used for Q6 because of its low voltage drop. The 50 A unit is used for Q4 and Q5 quadrupoles. Except the Q6 unit, the regulators are capable of shunting the required current in 2.0 GeV as well as 2.5 GeV operations. For the shunt regulator, a power transistor is employed as a linear switching device. The transistor operates in its linear

0-7803-4376-X/98/$10.00 © 1998 IEEE

active region. In this design, it is easy to control the current amplitude remotely. Quadrupole magnet power supplies have the stability and the ripple better than ±0.005 % and ±0.5 %, respectively. The power supply has its own controlling ability to maintain the required stability and ripple. As long as the shunt regulator current varies within the main current dynamics, the power supply preserves its characteristics. However, during turn on and off of the shunt, transients exist and may affect the main current dynamics. Therefore, it is necessary to adopt slow start and stop functions in the shunt control circuit which can be realized with hardware as well as software routines. The shunt circuit also has a current regulation function by using a current feedback loop. The transient phenomenon appears more significantly on Q1, Q2, and Q3 than Q4, Q5, and Q6. This is because, for the Q1, Q2, and Q3, small number of magnets is connected in series and thus shunt current variations can easily be detected by the power supply controller. Since the operating voltage of quadrupoles is as high as 422 V as listed in Table 1, an electrical isolation of the shunt circuit is considered in the design of the regulator.

*3.2 Configuration of Shunt Regulator*

A detailed circuit of the transistor shunt regulator is shown in Fig. 1. The power module that handles the shunt current is consisted of fifteen MJ5015 transistors. The transistor has 15 A, 120 V, 180 W specifications. Its typical current gain is about 70. The power module is mounted on a heat sink and electrically isolated from the metal case. Forced air cooling is selected to simplify the electrical isolation. In order to balance current sharing among transistors, a high precision 0.1Ω resistor is connected in series with each transistor. A free-wheeling diode module is also connected in parallel with the magnet. The transistors in the power module are commonly driven by a Darlington pair. The shunt current amplitude is detected by a DC current transducer (LAM Module LA50-P) and a bulk metal foil resistor (Vishay VHP-3, 100 Ω). The current transducer has an accuracy of ±0.5 %, an isolation voltage of 2 $kV_{rms}$, and a linearity of ±0.1 %. The resistor has a tolerance of ±0.01 %, and a temperature coefficient of resistance of ±5 ppm/°C. The sampled current is amplified and fed back to an error amplifier. At the amplifier, the feedback current signal is compared with a DAC reference. Then, the error amplifier output drives the Darlington pair to achieve the current regulation of the shunt. A gain-bandwidth product of the error amplifier is chosen as 1.592 kHz in order to minimise a high frequency noise response of the shunt controller. A high frequency switching noise exists in the main power supply current. There is also a soft start circuit when the shunt is turned on. This reduces turn-on transients that can influence the control dynamics of the main power supply. The soft start can also be realized by a control software of DAC reference.

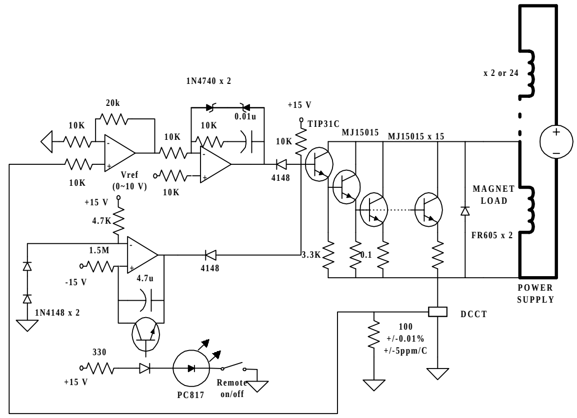

Figure 1: Transistor shunt regulator circuit.

The whole shunt assembly that includes the power module as well as the feedback control board is floated and electrically isolated. The electrical isolation between internal and external circuits is achieved by using PC817 photo-couplers (5 $kV_{rms}$ isolation), ISO122P isolation amplifiers (1.5 $kV_{rms}$ isolation), and transformers. In the shunt regulator, there are also self protection functions such as over-current and over-heating. It also contains a 12-bit DAC to generate a current set value. These functions are not shown in Fig. 1.

*3.2 Shunt Regulator Controller*

Each shunt regulator controller is assembled as a separate unit. The controller sends various commands to the shunt via a parallel data bus. It also receives a current reading and status from the shunt. In addition, the controller communicates with the PLS main control computer via a RS232C port. A TMS320C32 DSP is used for the controller. It can function as an independent processor unit, and local as well as remote operations are possible.

## 4 EXPERIMENTAL RESULTS

A plot of Q2 quadrupole current change is shown in Fig. 2 when the shunt regulator is turned on and off. The result is obtained at the 2 GeV operation. At this energy, the Q2 current is 83.352 A. The shunt current amplitude in Fig. 2 is 0.871 A or 1.04 % of Q2 current. As shown in the figure, there exist transients at the turn on and off instances. However, the transients do not kill or significantly affect the stored beam current. With the shunt operation, the magnet current stability is maintained except during the transients. The stability requirement of quadrupole current is better than ±0.005 %.

A ripple oscillograph of the Q2 current is shown in Fig. 3. In the figure, two waveforms are compared. The top ripple is measured when the shunt is off and the bottom is measured when the shunt is on. The waveforms are obtained during 2.0 GeV beam operation. The quadrupole current is 83.43 A, and the shunt current is 8.75 A which shunts 10.48 % of the quadrupole current. From Fig. 3, we can realize that no considerable ripple

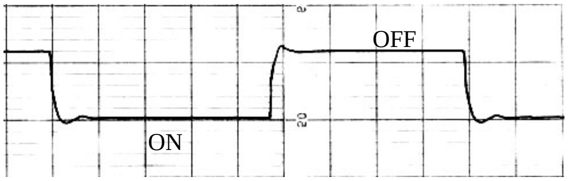


Figure 2: Variation of Q2 quadrupole current during a shunt regulator operation (3.0 sec/Div.). The Q2 current is 83.352 A with shunt-off and 82.481 A with shunt-on.

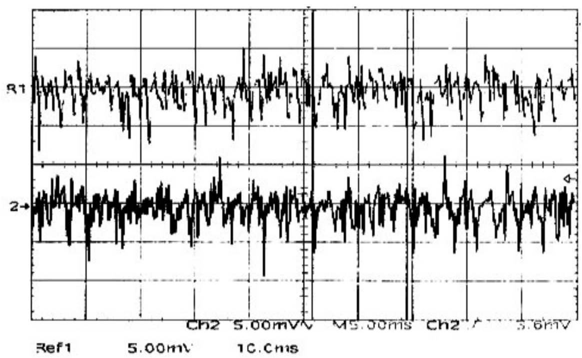


Figure 3: Ripple of Q2 quadrupole current (0.075 A/Div., 5 ms/Div.). Top: Shunt off, Bottom: Shunt on.

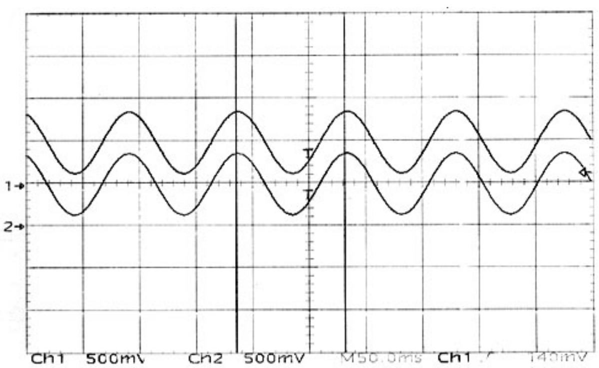


Figure 4: Comparison of a command signal (top) and a shunt current (bottom) of Q2 at a 10 Hz AC operation. Q2 current: 83.36 A, DC offset shunt current: 1.22 A, AC current: 1.8 A.

increment is detected. The ripple requirement of quadrupole is better than ±0.005 %.

The shunt can be operated in DC as well as AC modes. Even though the AC mode operation is not necessary for the BBA, we test the shunt in the AC mode to extend its capability that can be useful for other applications. In Fig. 4, a result of the AC mode operation is shown. The top wave in the figure is a shunt command, and the bottom is the measured shunt output current. As seen in the figure, the shunt current follows the command signal very smoothly and precisely. Due to the time constant limit of the quadrupole magnet, a useful operating frequency is expected to be less than 10 Hz. During the AC mode operation, a ripple is also measured. The AC shunt current gives some effect on the ripple content of the main magnet current. About 10% of the shunt current is superposed on the ripple.

In the PLS, total 108 BPMs are installed to collect beam position data. Preliminary measurement of BPM offset with the shunt regulator shows better than a 10 μm calibration accuracy. The enhancement of BPM calibration is also beneficial to the reduction of the closed orbit distortion. At present, the overall closed orbit distortion is no better than 500 μm (rms). Our goal is to enhance the electrical offset of all BPM less than 10 μm (rms) and also the closed orbit distortion less than 50 μm (rms) [2].

## 5 CONCLUSION

In order to enhance a calibration accuracy of BPM in the PLS storage ring, a BBA system is developed and installed. To realize the BBA system, it is required to control each quadrupole magnet current independently. However, the quadrupoles are grouped and connected in series, and each group is powered by a power supply. Therefore, a transistor-type high current shunt regulator is developed to perform the BBA function. It can shunt more than 10 % of main magnet current while maintaining current specifications. The shunt regulator shows satisfactory performance during preliminary tests. It also performs nicely in an AC mode operation. Preliminary calibration of a BPM using the shunt is also carried out. The result shows that a BPM calibration accuracy of less than 10 μm (rms) can be achievable. The result also indicates that the closed orbit distortion of less than 50 μm (rms) is also possible. The 50 μm (rms) is about an order of magnitude improvement from the present value of closed orbit distortion.

## 6 ACKNOWLEDGEMENTS

This work is supported by POSCO and MOST of Korea. We are grateful to our colleagues, especially Mr. S. H. Jung, and Mr. S. H. Han at PAL, for their support during the work.

## REFERENCES

[1] I. Barnett et. al., "Dynamic Beam Based Alignment," 2nd European Workshop on Beam Diagnostics and Instrumentation for Particle Accelerators, DESY M-95 07, pp. 38, 1995.

[2] J.Y. Huang, D.H. Jung, S.H. Nam, M. Yoon, I.S. Ko, "Beam Based Offset Calibration of the PLS BPM," in this proceeding.