ACTIVE SHUNTS FOR THE LNLS STORAGE RING QUADRUPOLES

C. Rodrigues, A. R. Silva, LNLS, Campinas, Brazil.

Abstract

The quadrupoles of the LNLS storage ring are divided into families with two or six units, each one being supplied by an only current source. Some experiments performed by the accelerator physics team require different currents for quadrupoles of a same family. Moreover, there is an interest in obtaining lower steps in the control of their currents. These were the main reasons that required the development of an active shunt.

A prototype was built with range of -3A to +3A, what is approximately 3% of the maximum quadrupole current (200A). It was tested with a two-quadrupole family power supply.

The full bridge topology was chosen, where the pulse width for the positive and negative output voltages are not the same, which gives an average output current different from zero.

Some waveforms and results are shown, such as the long-term stability and output current ripple. Some measurements made in the storage ring electron beam using the active shunt are also described.

INTRODUCTION

The Light Source of the Brazilian Synchrotron Light Laboratory (LNLS) is based on a 1.37 GeV electron storage ring, a 500 MeV Booster Synchrotron Injector and a 120 MeV LINAC [1].

There are 36 quadrupole magnets in the storage ring, which are grouped in families of 2 or 6 units, in a series association, each family being fed by one power supply.

Some experiments, such Beam-based Alignment (BBA) or betatron tune measurements, need slightly different currents in quadrupoles of a same family. In this case active shunts can be used. Other possible active shunt application is to get higher resolution sets of the quadrupole currents.

The conventional active shunt consists, basically, of a semiconductor device, such as a Bipolar Junction Transistor (BJT) [2] or Metal-Oxide-Semiconductor Field Effect Transistor (MOSFET) [3], put in parallel with the magnet and working in the linear region, so it can be seen as a variable resistance. This topology has the disadvantage of dissipating a high power at the semiconductor. Moreover, the current in the magnet which it is connected in parallel may only be decreased.

If switched converters are used, the power dissipated in the semiconductor switches is low and the energy drawn back from the magnet can be dissipated on a resistor or partially used to feed the circuit [4].

The chosen topology was the full-bridge, because it is fed by a single voltage and it allows increasing or decreasing the magnet current. Additionally, the LNLS has already used this topology in other applications [5].

CIRCUIT DESCRIPTION

Fig. 1 shows the Active Shunt connection to the magnets and Main Power Supply. The magnets Mg_1 and Mg_2 are represented by a resistance R and an inductance L. The Main Power Supply is simplified as a rectangular voltage whose duty cycle is adjusted so the desired average value of current i(t) is obtained. For the two-quadrupole family power supplies, the two values of this voltage are zero and 40V.

The Active Shunt is represented by a rectangular voltage with a series inductance. In this case the voltage values are symmetrical ($+V_{cc}$ and $-V_{cc}$) and the duty cycle controls the average value of current $i_s(t)$.

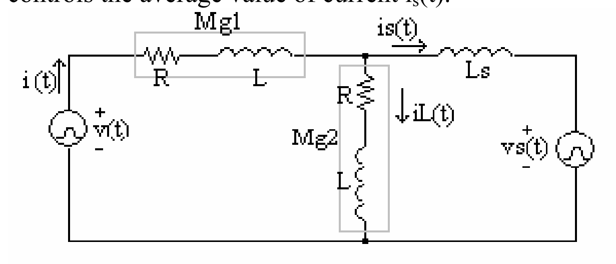

Figure 1: Active Shunt connection with magnets and Main Power Supply.

Fig. 2 shows the Active Shunt simplified circuit. It consists basically of a bidirectional full-bridge with an inductance L_s in series with its output.

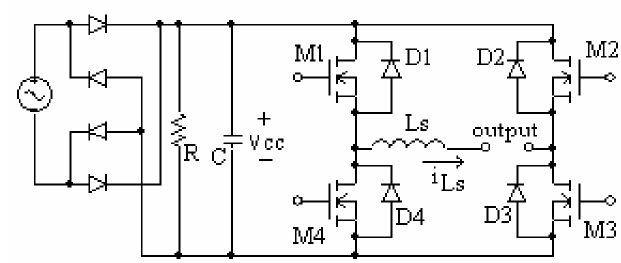

Figure 2: Active Shunt simplified circuit.

The feeding V_{cc} for the bridge is obtained from a conventional rectifier connected to the AC line by a transformer (not shown) and with a capacitor C used as filter. This capacitor must be large enough to absorb the energy from magnet during transients. The resistor R is necessary to dissipate the energy from magnet in the steady state when the active shunt is decreasing the magnet current, otherwise the voltage V_{cc} would increase. All control circuits are also fed by this voltage through auxiliary regulators, so they help the resistor R to dissipate the received energy. The V_{cc} value must be higher than the maximum voltage drop over the magnet so the active shunt can increase or decrease the magnet current. Because of this magnet voltage drop, it is easier to decrease the magnet current than to increase it.

1-4244-0917-9/07/$25.00

The full-bridge output voltage and current, and the diodes and switches conduction intervals are shown in Fig. 3, for two situations, first when the active shunt is increasing the magnet current and the second when it is decreasing. δ_s is the full bridge duty cycle and F_s is its switching frequency.

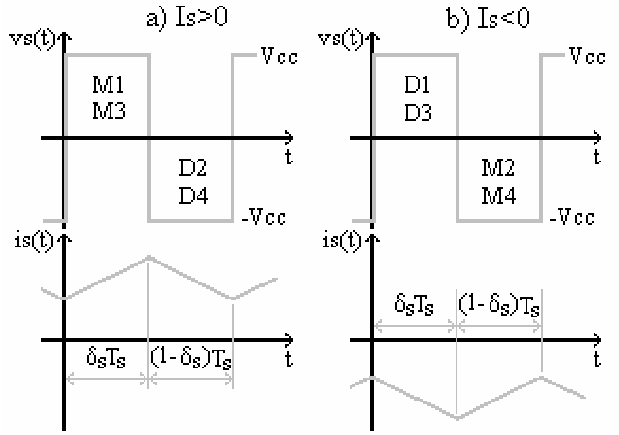

Figure 3: Full-bridge output voltage and current for is>0 (a) and is<0 (b).

The duty cycle δ_s does not depend on the active shunt current, and it is given by Eq. 1. The voltage v(t) has only two possible values, so there are two stable values of δ_s.

$$\delta_s = \frac{1}{2}\cdot\left(1 + \frac{v(t)}{2 \cdot V_{CC}}\right) \quad (1)$$

During the interval $\delta_s T_s$ M_1 and M_3 are turned on, and they are turned off during the interval $(1-\delta_s)T_s$. M_2 and M_4 are commanded in the opposite way. L_s is high enough so the converter operates in the continuous conduction mode for most of the active shunt current range. Only for low active shunt currents does the converter operate in the discontinuous conduction mode.

If the average value of i_{Ls} is negative, the diodes D_1 and D_3 conducts instead of M_1 and M_3 during the interval $\delta_s T_s$. In this case the active shunt will be increasing the current in the magnet and the active shunt will be providing energy to magnet.

Otherwise, if the average value of i_{Ls} is positive, the diodes D_2 and D_4 conduct during $(1-\delta_s)T_s$ instead of the MOSFETS M_2 and M_4. The active shunt will be decreasing the current in the magnet connected across the output. So, the active shunt will be receiving energy from the main power supply.

The control technique used is Pulse Width Modulation (PWM) with fixed switching frequency. The compensator is based in a proportional-integral (PI) circuit.

EXPERIMENTAL RESULTS

A prototype was built and tested with a two-quadrupole family power supply, with range of -3A to +3A. This range corresponds to approximately 3% of the maximum quadrupole current (200A).

Fig. 4 and 5 show the current ripple, respectively for 3A and -3A active shunt current with the main power supply current set to 150A.

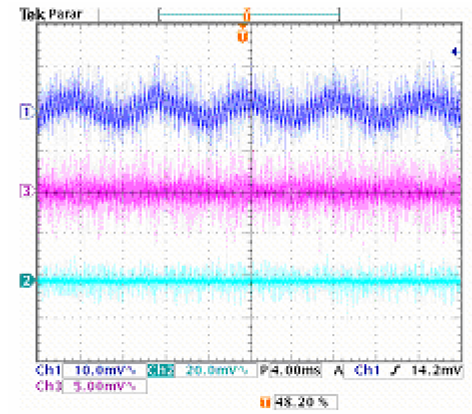

Figure 4: Current ripple for 3A active shunt current: Ch1: active shunt: 10mA/div (upper trace), Ch3: main supply: 150mA/div (middle trace), Ch2: parallel magnet: 500mA/div (lower trace).

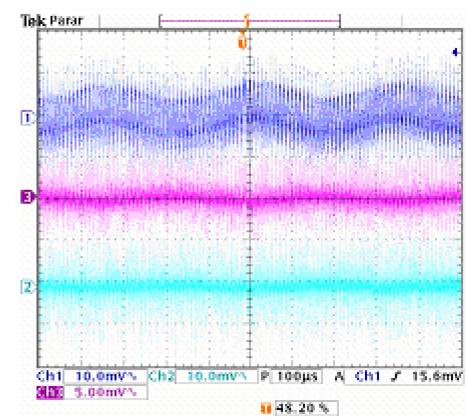

Figure 5: Current ripple for -3A active shunt current: Ch1: active shunt: 10mA/div (upper trace), Ch3: main supply: 150mA/div (middle trace), Ch2: parallel magnet: 500mA/div (lower trace)

Transition tests in the active shunt current were performed and no effects in the main power supply were observed. The active shunt current steps during these tests were 6A (from -3A to +3A and from -3A to +3A). Fig. 6 shows the waveforms for a transition from +3A to -3A in the active shunt output current.

Stability tests were done and the result was observed through the electron beam orbit measurement. During 24 hours the active shunt current was held in 0A, and during more 24 hours in 2A. No additional orbit variations were observed than those observed during a users common turn.

1-4244-0917-9/07/$25.00 ©2007 IEEE

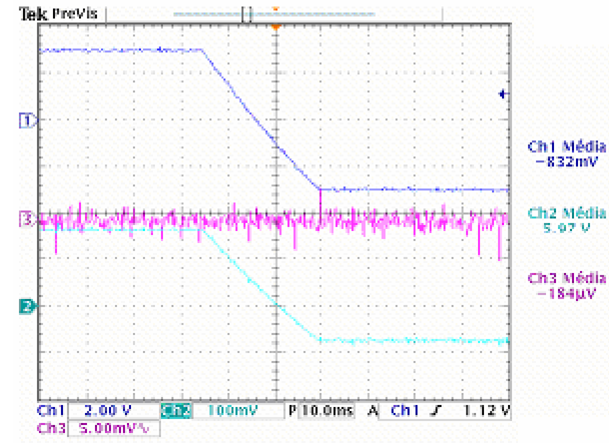

Figure 6: Active shunt reference voltage step response: Ch1 (upper trace): active shunt current (2A/div), Ch3 (middle trace): main power supply AC current (150mA/div), Ch2 (lower trace): parallel quadrupole current (2.5A/div, offset -150A).

The prototype was also used for beam-based alignment (BBA) and betratron tune measurements. Fig. 7 shows the result for the BBA in one quadrupole.

CONCLUSION

The prototype has shown until this moment good results and worked as expected. No deleterious effects were observed in the main power supply or in the electron beam. The range seems to be adequate to BBA and betratron tune measurements, as shown by the tests.

The capability to increase or decrease the magnet current without to need changes in the main power supply current showed to be very convenient.

A second prototype is being built for +5A/-5A range and some other improvements, such as Feed-Foward control.

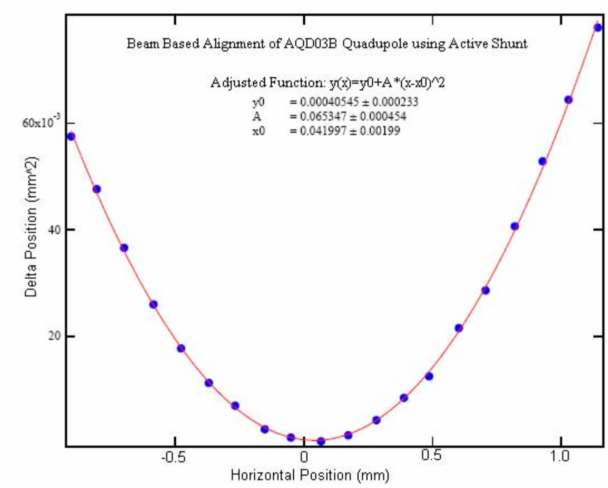

Figure 7: BBA for one quadrupole using active shunt.

Another one of these improvements is the use of a controlled resistance to dissipate the energy received from the magnet, what would allow it to dissipate a power proportional to the active shunt current. It would decrease the internal heating and would increase the circuit efficiency, without allowing the capacitor voltage to increase. Other possible and better alternative for this problem is the development of a converter that gives this energy back to the electric line, what is being studied.

REFERENCES

[1] www.lnls.br

[2] S. H. Nam, J. H. Suh, K. M. Ha, J. Y. Huang and I. S. Ko, “A High Current Shunt Regulator For Quadrupole Magnets In PLS 2GeV Storage Ring”, PAC’97, Vancouver, May 1997, p.3479.

[3] E. J. Martin, N. Dobeck, G. S. Jones and M. K. O’Sullivan, “A 20A Shunt Regulator For Controlling Individual Magnets In A Seriesed String”, PAC’95, Dallas, May 1995, p. 1973.

[4] M. Berndt, C. Guracar and J. Lipari, “A DC Chooper Used As An Adjustable Current Bypass Shunt”, IEEE Transactions On Nuclear Science Vol. 22 No. 3 (1975).

[5] J. G. Oliveira, C. Rodrigues, “Projeto de Uma Fonte de Corrente Bipolar com Saída Full-Bridge”, *CBA’06,* Salvador, October 2006, p. 1891.

1-4244-0917-9/07/$25.00