DESIGN POWER SUPPLY CONSIDERATIONS TO COMPENSATE BOOSTER POWER SUPPLIES EFFECTS ON THE SOLEIL STORAGE RING

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Abstract

The booster power supplies influence the storage ring beam position in synchrotron SOLEIL.To compensate these disturbances, a dedicated wire loop fed by an in-house developed power supply (PS) was installed in the booster cable tray. The power supply output current is driven by direct measurement of the 3Hz booster power supplies. This paper discusses the PS requirements according to beam position measurements and the original design. Finally the orbit stability improvements when this power supply is switched on are presented.

INTRODUCTION

Since 2009, top-up mode has been routinely in operation for various electron bunch filling patterns at synchrotron SOLEIL[1]. The electron beam stored current is maintained within 1% in the 2.75 GeV storage ring. For each injection, the following sequence is applied. The 3 Hz booster PS current are raised from 0 A to their nominal values 9 seconds before injection trigger, after checking that all equipment are ready for injection and sending gate signal to users (even though it is not used), the beam is injected and finally the 3 Hz PS currents are back to 0 A during 5 seconds. Electrons are produced by a 90 keV gun then accelerated to 110 MeV by the LINAC, injected to the booster for increasing their energy to 2.75 GeV in 167 ms, and finally injected into the storage ring (SR) (Figure 1). A full injection sequence lasts 15 seconds.

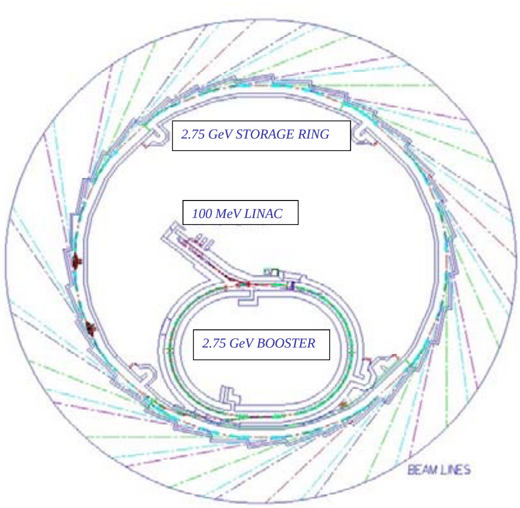

Figure 1: Layout of the SOLEIL accelerators: linac, booster, storage ring, and beam-lines.

When the booster power supplies are working at nominal values, the stored beam orbit stability is impacted at two levels: a DC component modifies the closed orbit and a 3 Hz component is visible on the storage ring cells closest to the booster tunnel. Some beam-line source point positions vary up to 10-20 µm in the horizontal plane and the amplitude of the 3Hz perturbation is multiplied by a factor 9 (without running fast orbit feedback system). When ramping the PSs from 0 A to nominal values the situation is worse by a factor 2 to 3 for the tracking between booster PSs is not as effective as in nominal regime. The orbit noise is not induced on the BPM electronics but directly on the electron beam by the current loops of dipole, quadrupole, and sextupole magnets.

To cancel out these disturbances, a specific wire loop was installed in the booster cable tray. A reverse current to booster PSs is fed into this loop, generated by a dedicated in-house developed power supply.

SOLEIL BOOSTER

The 157 m long booster is hosted inside the 354 m long storage ring in a separated tunnel connected by a 40 m long transfer line as shown in Figure 1.The booster PSs are located in an outside specific hall with one wire loop for each magnet family in the booster.

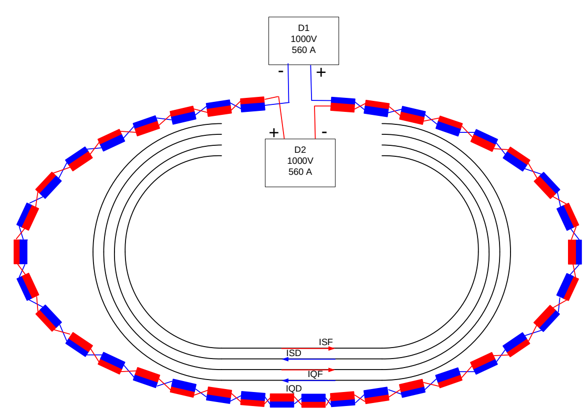

Figure 2: Power supplies connections of dipole (D1, D2), quadrupole (QF, QD), and sextupole(SF, SD) magnets.

Each of the 36 dipole magnets has interleaved upper-lower coils connections from two PSs (D1 and D2) in order to keep low voltage value (<1000V). The tracking tolerance error between these two PSs is less than 10^{-3}. The currents are in opposite direction in the tunnel to minimize current loop effect (Figure 2).

The quadrupole and sextupole magnets are split in focusing (QF, SF) and defocusing (QD, SD) families fed by a total of four independent power supplies.

The power supplies (except SF) are controlled with 3 Hz cosine waveforms and offset signals (Figure 3):

$$\mathrm{i}(t) = I\,\frac{(1-\cos\omega(t-t_0))}{2} + I_{offset},$$

where I is the PS peak to peak current, Ioffset an offset current, and ω the 3 Hz angular frequency.

The 3 Hz SF power supply waveform is a truncated cosine shape in order to limit the heating up of the non-water cooled sextupole magnets (lower Figure 3).
All main PS parameters are given by Table 1.

Table 1: Nominal Parameters (Main and Offset Current) of the Booster Power Supplies.

Magnets	$I_{peaktopeak}$ (A)	I_{offset} (A)
D1	545	-0.1
D2	545	-0.1
QD	160	-0.78
QF	200	-0.73
SD	16	-0.7
SF	15	0.6

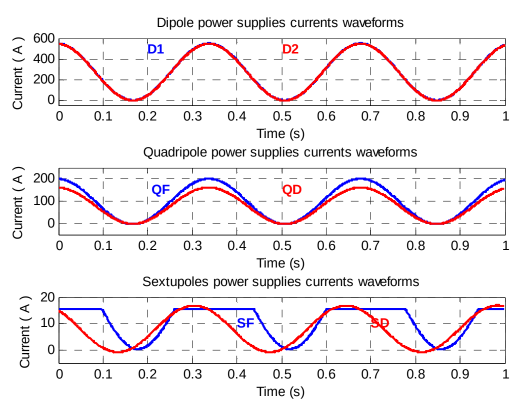

Figure 3: Waveforms of dipole (top), quadrupole (middle) and sextupole (bottom) power supplies.

COMPENSATION POWER SUPPLY

Preliminary tests showed that driving a simple wire loop (located in the booster tunnel) with a current shifted in phase and proportional to the main current booster PS reduced significantly the SR beam orbit distortion. A power supply able to produce an AC current of 140 Apeak@70 A DCwith a voltage of 24 V was developed in-house. The SLS (Swiss Light Source) digital control was adopted as described in Ref. [2] (same one as for the dipole, quadrupole and sextupole PSs). A DSP-FPGA based control board determined the duty cycle to apply to each switch in respect to an analogue reference input or with a memorised waveform.

Twosingle phase inverters were associated with interleaved controland parallel output. Each inverter has a standard regulated AC/DC source.

As a first step, the reference input of the compensation power supply is get directly from the current measured on the booster PSs. For each power supply family, parameter values were experimentally determined (DC ratio, AC ratio, and phase shift) to reduce the influence on the storage ring beam position.

A first surprise concerned the two dipole PSs effect: although they supply two identical currents circulating in opposite direction inside the tunnel the current loops are not completely cancelled out. An additional compensating current is required (about 6 % of the dipole current value).

The focusing and defocusing quadrupole magnets are also connected in opposite direction in the tunnel in order to limit the influence on the storage ring beam position. In this case, the needed compensating current is closed to the expected value which was estimated to be the difference between the focusing and the defocusingquadrupole currents.

The sextupole currents are different from waveform point of view. A separated compensation is necessary for each family with a compensating current value close to each PS main value.

The principle of the control is given in figure 4.

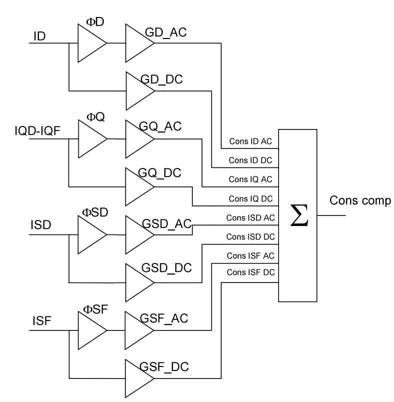

Figure 4: Control functional diagram.

Using this compensation principle, performance limitations are listed hereafter:

- The current measurement and signal processing introduce a delay with respect to the reference signal and therefore limit the compensation performance during the ramping of power supplies.
- As the SF current waveform is a truncated sine waveform, it is difficult to obtain the best compensation waveform with analogue signal processing.

A digital feed forward was implemented to level off the limitations. For each PS family, the compensation waveform is determined experimentally in respect to the control diagram Figure 4. Then the waveform signals are added and memorized in the control board.

Through the control system, a device drives simultaneously the compensation PS and the booster PSs. The amplitude of the compensation power supply is proportional to the peak current of the booster PSs both in 3 Hz steady state, and during ramping phases from 0 A to nominal currents or from nominal values to 0.

ORBIT STABILITY IMPROVEMENT

The use of the compensation loop has improved the stability of the storage ring horizontal closed orbit. Typically the DC perturbation has been dropped from 12 µm peak down to less than 1 µm. The 3 Hz component is cancelled out and reduced by a factor 9 close to the level when the booster PSs have no current (See Figure 5 and Table 2 for details). In addition, thanks to the digital compensation, the transient effect during the ramping of PSs from 0 A to nominal values is levelled off (Figure 6).

CONCLUSION

The booster compensation loop has been put into operation since July 2010. It was successfully integrated in the control system and top-up application. The equipment is very reliable and participates to the improvement of the storage ring orbit stability.

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Table 2: Orbit perturbation (DC and AC part) when the booster power supplies are running with and without the compensation loop

Configuration	3 Hz line (µm RMS)	DC orbit (max µm)
All PSs off	0.2	0
D1,D2: loop off	1.3	5
D1,D2: loop on	0.2	< 1
QF,QD: loop off	1.1	4.5
QF,QD: loop on	0.2	<1
SD: loop off	0.5	3
SD: loop on	0.2	<1
SF: loop off	0.5	2
SF: loop on	0.5	<1
All PSs on: loop off	1.8	12
All PSs on: loop on	0.2	<1

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[2] F. Bouvet, "Design of the DC and AC magnet power supplies for the SOLEIL synchrotron radiation source", EPE'09, Alborg (2009).

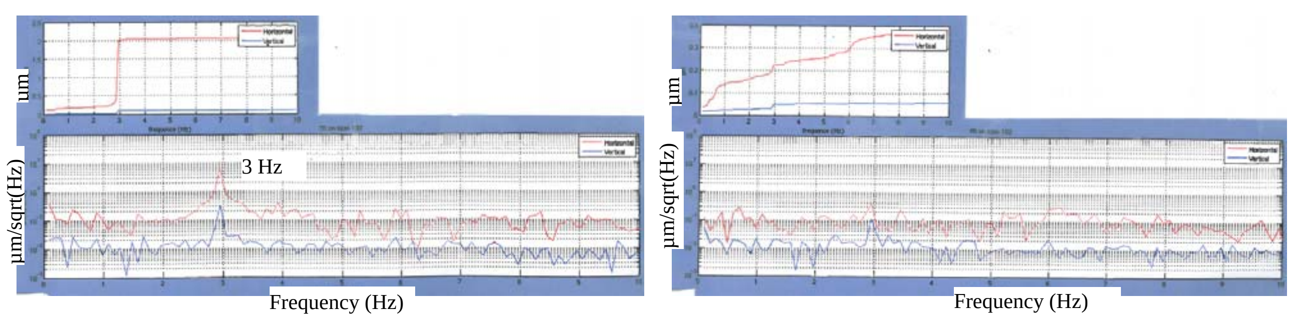

Figure 5: Horizontal orbit noise in steady state in the range 0-10 Hz without (left) and with compensation loop (right).

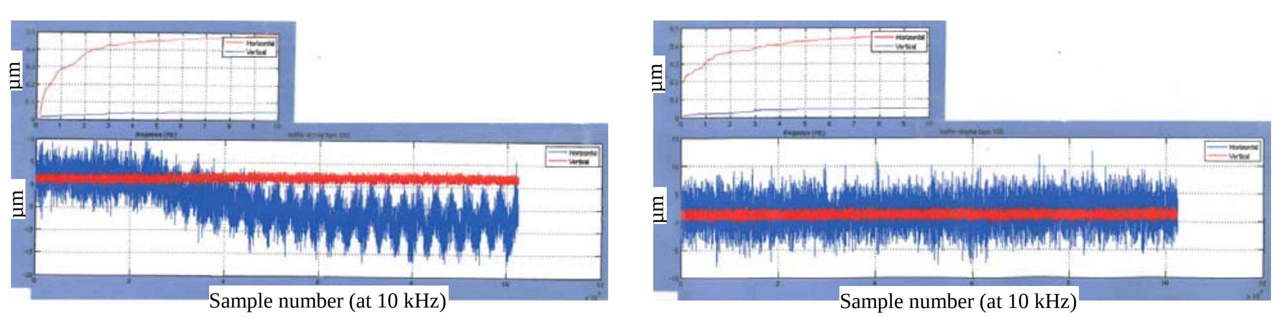

Figure 6: Horizontal transient orbit during PSs ramping without (left) and with (right) compensation loop observed on a storage ring BPM located closed to the booster tunnel. Without compensation, the closed orbit has both a DC drift and a 3Hz perturbation.