A BESSY-1 6 TESLA WLS EFFECT COMPENSATION SCHEME

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I. INTRODUCTION

A WLS (superconducting wavelength shifter) is now in operation in the BESSY-1 storage ring. The maximum field therein is 3.25 T(esla). To its weak effect on the stored beam, so far no compensation in quadrupole strengths is needed.

It is planned to install a 6 T WLS to replace the present one. A study on its effect and compensation considerations is carried out in 1994 by the authors, then as visitors to BESSY.

The WLS has first to be characterized in terms comprehensible to commonly used machine physics computer codes. The work involves field analysis, particle tracking, transport matrix calculation and modeling of the field with piecewisely constant magnets, and is described in another note[1]. The calculations for the 3.25 T WLS are in good agreement with observations. The work presented in this paper is based on the modeling, that is, the model magnets are put in the place of the WLS for all the relevant calculations. The 6 T WLS field in the modeling is scaled up from the 3.25 T WLS field measurement data; so it may differ from the real field in the future WLS.

According to the study, the 6 T WLS will have quite annoying effects on linear optics and non-linear/chromatic beam behavior, inducing beta function beatings and depressing the dynamic aperture, especially for off-energy or off-x-axis particles.

A compensation scheme with 4 additional independent quadrupole power supplies is hence proposed. The beta function beatings can be fully localized in the WLS seated drift section, while the superperiodicity and symmetry of the lattice functions be saved to a large extent. The tunes are the same as in the currently operational optics. The quadrupole strengths are optimized to assure a sufficiently large dynamic appeture.

The authors are not to declare that such a compensation is absolutely necessary, because of the uncertainty about the real field and about interactions between the WLS's disturbance and existing magnet errors and misalignments. But rather, this paper is to present that, if a compensation is needed, how it should be made and what it can achieve.

II. EFFECT OF THE 6 T WLS IN BESSY-1

The lattice configuration now in operation is named as "WLS" optics. To avoid confusion, we refer to the original WLS optics as "WLS-0", in which the WLS field is zero; the configuration with 6 T WLS on but "No Compensation" (with the same quadrupole settings as in WLS-0) is refered to as "WLS-NC"; and the proposed configuration, with the WLS on and new quadrupole settings for compensation, as "WLS-C".

The main magnet strength settings, ring parameters and lattice functions in all the configurations are given in tables and/or figures in a BESSY technical note[2]. In any case, the sextupoles are set to correct the chromaticities both to plus one.

The linear lattice calculations and function fittings are made with the authors' self-developed codes ⟨LAMP⟩ and ⟨LATGH⟩. The latter features graphic output based on CERN-developed software package HIGZ and interactive execution mode. Particle tracking and other non-linearity and chromatism studies are fulfilled mainly with ⟨PATRICIA⟩[3], to which a few additions[4] by an author are found useful in the studies, like harmonics analysis in an asymmetric ring.

In WLS-0, the beta functions are well matched, with the tunes as ν_x/ν_y = 5.619/3.284, and with maximum β_x/β_y = 16.1/14.0 m.

When the 6 T WLS is turned on, a strong vertical focusing and a relatively weak horizontal defocusing are exerted on the beam. Its most eye-catching effect is that on the two beta functions. The β_y beating amplitude is as high as 1/4 of the β_y peaks, making the original peaks fluctuate a lot. The β_x function is also distorted. The tunes shift to 5.601/3.324, and maximum β's rise to 18.8/17.4 m.

The DA(dynamic aperture)'s shrink obviously, especially for particles with large energy deviations and hence falling into synchrotron oscillations. On-energy particles with $15\sigma_x \times 15\sigma_y$ betatron oscillation amplitudes can stay in the ring, but those with 20×20 σ's get lost.

The effect of the 6 T WLS seems more serious than anticipated. The vertical focusing, always the strongest part in the 1st order effect, can be estimated with the integral value of the WLS field ($1/\rho$) squared. A previous technical note[5] estimates the vertical focusing element M(4,3) would be -0.51(m^{-1}). Provided that the 6 T WLS field is in proportion to the 3.25 T WLS field, the integral will be 20% larger, because its on-axis field distribution differs from that anticipated (see [5,6]), in which the positive central field is sharper and the negative side fields flatter. The effect goes further beyond because the beam orbit lies off-axis in the central field where, due to the 2nd order field descending with x, the beam sees a negative $\partial B_y/\partial$x and is horizontally defocused as well as vertically more focused. As obtained from tracking, the M(4,3) term goes to -0.73, altogether 43% larger than the anticipation; and the horizontal defocusing term M(2,1) is 0.115, big enough to cause trouble in x-plane oscillation.

There are several factors that also depress the DA. The superperiodity and symmetry of the lattice functions are seriously broken. This is made worse by the "asymmetric location" of the WLS, whose center is 30 cm away from the straight section center. The phase advances between the sextupoles are changed, not only $\Delta\phi_y$ but $\Delta\phi_x$ as well. For off-energy particles, the big beatings in the β's are superposed with their chromatic beatings, which are quite big even in WLS-0.

The tunes in WLS-NC can be adjusted back to the old values with the existing quadrupoles. Many options are tried but none is satisfactory, with the β distortions on the same scale, if not larger. This proves that an asymmetric disturbance can hardly be pressed down by symmetrically located means.

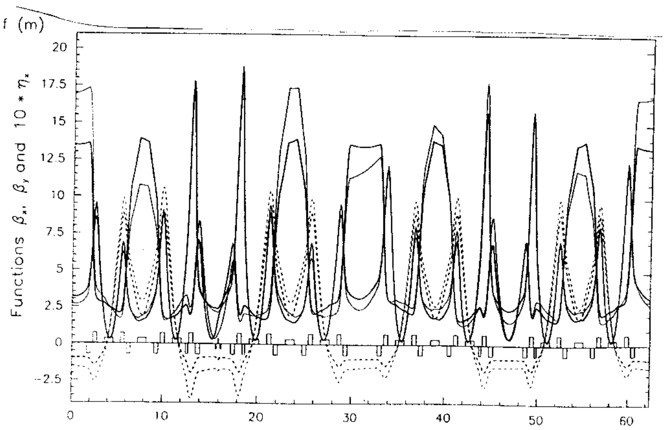

Figure 1. Lattice Functions in WLS-C/WLS-NC

III. THE COMPENSATION SCHEME

To fully correct the β distortions, at least 4 more "variables" are needed and all of them must be "asymmetric", that is, independent of other ring components. The proposed scheme requires 4 quadrupoles to be excited separately. They are the 4 closest to the WLS location, named as Q2A, Q1A, Q1B and Q2B, respectively, in the sequence as in the beam motion. Q2A and Q2B belong currently to the QT2 family, similarly for the Q1's. In WLS-C, their K1 values (normalized field gradient, in m^{-2}, positive if horizontally focusing) are: Q2A, Q2B = 4.7011, 4.4402; Q1A, Q1B = -3.7587, -2.8912. (cf. QT2, QT1 = 4.5423, -3.3352 in WLS-C or 4.5741, -3.3787 in WLS-0.)

The lattice functions (β_x, β_y and $10\times\eta$) in the whole ring are plotted in Fig.1, which compares the functions with those in WLS-NC by plotting the latter in thiner lines as a background.

The WLS-C returns to the WLS-0 working point, and gets rid of the big beta function beatings, having maximum β_x/β_y = 18.0/13.9 m. The linear disturbance of the WLS effect is fully localized in the WLS seated section, or between Q2A and Q2B. The supeperiodicity and symmetry of the lattice functions are saved to a large extent. The β_y peaks, that at the injection point included, are kept roughly the same as in WLS-0. This is good for beam injection performance. And, for all the lattice functions in the bending magnets, WLS-C and WLS-0 make little difference (while WLS-NC makes some). This should be good for the photon beamline users. The new quadrupole power supplies increase the flexibility of the ring lattice, by which other improvements can be made possible. For example, the authors intentionally reduce the η function fluctuation so that the beam emittance in WLS-C is down to 34 nm-rad, about 30% lower than that in WLS-0 to gain a factor of 2 increase in the photon beam brightness, and a little lower than the emittance in Super ACO, which is sometimes taken as a marker of the level of those so-called 3rd generation light sources.

Fig.2 gives tracking results for the configurations. Shown are DA's for particles with energy oscillation at an amplitude of 0.5% dE/E (about $8\times\sigma_E$), printed at the injection point, roughly of the size of the physical aperture, horizontally $\pm$ 10 mm and vertically 20 mm high, filled with characters to mark the starting positions of the particles, "*" for those who survive the 1000 turn tracking in WLS-C or "o" for those who fail to. The DA in

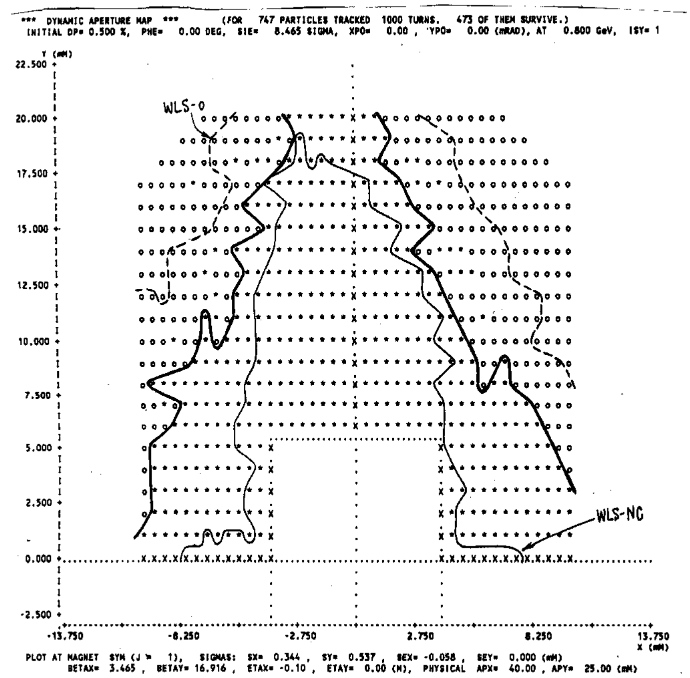

Figure 2. Dynamic Apertures for Off-energy Particles

WLS-C is then drawn to include the survivors, with the DA's in WLS-NC and in WLS-0 drawn with thin lines and broken lines, respectively, for comparison. Also tracked are on-energy particles and a few typical particles, whose betatron oscillations start with 10×10 to 25×25 σ's, with the σ's as the standard(r.m.s.) beam sizes, the horizontal one at zero coupling and the vertical at full coupling. Figures of on-energy DA's and phase space plots for the typical particles are omitted.

The DA's in WLS-C are obviously larger than those in WLS-NC, though still smaller than those in WLS-0 to a similar extent. The improvement is more substantial for particles of large amplitudes in energy oscillations or in vertical betatron oscillations. This should turn to longer beam lifetime and faster injection rate. As for the typical particles, a "15σ" particle may feel somehow the same in the 3 optics; but a "20σ" or even "25σ" particle experiences a big difference, finding himself stable in WLS-C but not in WLS-NC.

During the search for an ideal compensation scheme, some attempts to use less independent power supplies were made without success. The WLS is located at a "double-asymmetric" position, breaking the symmetry not only about the injection point but also about the center of the section where it is installed. To correct its influence, only the differences between those quadrupoles which used to belong to one family count as useful variables.

The more tricky part is about the DA or the tracking. We had a few somehow better-looking linear solutions that, unfortunately, turn out to be ugly in tracking calculations. It is not the case when we did similar work at NSRL, where we found a good linear effect compensating scheme and it behaves reasonably well in tracking studies. The NSRL machine, HLS ring, resembles BESSY-1 ring in many respects. But there are at least 3 differences to account for why non-linear effects in BESSY-1 are relatively difficult to cope with: 1) The WLS optics has a lower beam emittance, which usually means a more restricted DA. 2) There are fewer sextupoles in BESSY-1, so their strengths have to be higher. 3) The sextupoles in BESSY-1 are asymmetrically located, so the ring is, in the sense of higher order effects, an asymmetric ring. The optimization of the quadrupole strengths to assure a sufficiently large DA was time taking, in which main progresses are made with two key steps. First, $\langle$PATRICIA$\rangle$ is able to do harmonics analysis for a few sextupole strengths related functions, one of which is responsible for on x-axis particle motion. A component of $\sin(N\phi_x)$ is found too large, with N = 17, close to $3\times\nu_x$. The component should vanish if the ring has a superperiodicity of two (then no odd terms) or the ring is symmetric (then no $\sin$-terms). Efforts are made to lower that component and the on x-axis particles feel better. Second, for off x-axis particles, there must be coupling between the two transverse betatron oscillations. In BESSY-1 it is always the vertical amplitude that rises first, and the horizontal one follows. It is because, among the β's at all the sextupoles, β_y at the SD's is the highest. The particles get a vertical kick, proportional to its x and y displacements multiplied, at every sextupole. The kick may be thought as a vertical focusing force varying, from one sextupole to another, with the horizontal displacement x. If the horizontal phase advances between the 4 SD's are roughly equal, the additional focusing cancels over one turn. That is how the phase advances are distributed in WLS-0, and may be why the tracking is tough for far off x-axis particles in WLS-NC and in compensation schemes. The horizontal defocusing term, not big though, plays in this sense a bad role. From this understanding, we use fitting calculations to make (it sounds strange) the horizontal phase advances between the SD's as equally paced as possible, even at the cost that β_x is a little mismatched (and worse-looking, as shown in the figures). This step gains a lot in the DA.

IV. CONCLUSION

As described above, the proposed scheme can compensate the effect of the planned 6 T WLS, keep its disturbance under an acceptable level and make the performances of the BESSY-1 light source nearly the same as when the WLS is off.

The required hardware changes are four power supplies and associated wiring. The new power supplies may be of less ability than the currently used ones, or four controllable shunts across the quadrupoles, with the advantage that the configuration can return to normal by simply turning off the shunt currents.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

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