Some thoughts on magnet synchronization in the MAX IV 3 GeV storage ring

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Abstract

This note attempts to describe synchronization requirements for quadrupoles in the MAX IV 3 GeV storage ring when the optics have to compensate gap changes in strong insertion devices. The actual compensation procedure is described in detail in the DDR [1] and updated in MAX-lab Internal Note 20110117 [2]. It shall only be summarized briefly here. From this process we derive an estimate of how well different quadrupole power supplies have to be synchronized. Synchronization criteria for orbit correctors (slow and fast orbit correction) are not discussed in this note.

1 Introduction

During commissioning synchronization of quadrupole settings can be imperfect. Although quadrupole settings can be expected to change very frequently during commissioning, transient behavior resulting from non-synchronous application of magnet setting changes can be tolerated. In user operation however, we need to ensure that quadrupoles setting changes are applied in a synchronous way in order to ensure that overall gradient stability criteria are not spoiled. Such quadrupole setting changes are expected to take place on a frequent basis during regular user operation. The reason for this is that strong insertion devices (IDs) such as (damping) wigglers and in-vacuum undulators (IVUs) have a significant influence on vertical focusing

[1] This document can be found at `http://www.maxlab.lu.se/node/999`

(cf. MAX-lab Internal Note 20110117 Section 4 [2]). If such a strong ID changes its gap, the change in vertical focussing needs to be compensated both locally (optics matching to prevent beta beats) and globally (phase error compensation to restore the correct working point).

Damping wigglers are considered part of the lattice and hence they are operated either on (in/closed) or off (out/open). Consequently their compensation is either applied or not, but it does not vary during user operation. User ID gaps can however be expected to change frequently during user operation and hence the optics will need to be adjusted frequently to properly compensate these gap changes. In the following a scenario is described where a strong IVU is ramped from off (gap fully opened) to maximum strength (minimum gap) and the different compensation steps are detailed together with expected strength variations. This allows an estimate of the required synchronization.

2 Outline of optics tuning for ID compensation

For this example we take a strong ID like the IVU presented in MAX-lab Internal Note 20110117 Section 4 (parameters in Table 2) and look at what has to happen when this IVU's gap is brought from its fully opened position (IVU off) to its minimum setting (IVU at maximum strength). It is important to note that while this is not the most common mode of operation, it is not an untypical scenario and can be expected to happen during regular user operation. The duration of such a cycle is on the order of 10 s [3]. The most common operation will however be intermediate movements where the gap is changed from one setting to another nearby setting. This is a smaller change of ID strength, but it also happens on a correspondingly shorter time scale.

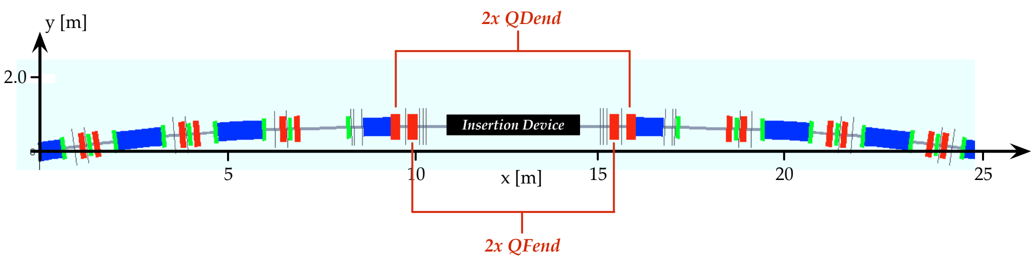

Figure 1: Location of the QFend and QDend magnets used to compensate locally for the effect of a strong ID installed in the long straight section in between.

According to MAX-lab Internal Note 20110117 Section 4 closing the gap of this

ID will require a local matching of the optics to compensate for the additional vertical focusing created by the closed gap of the ID. In this case, the setting of the flanking QDend magnets (two defocusing quadrupoles installed on either side of this specific IVU, cf. Fig. 1) have to be increased by 0.46%. Likewise, the setting of the flanking QFend magnets (two focusing quadrupoles installed on either side of this specific IVU, cf. Fig. 1) will have to be increased by 0.11%. It is foreseen to apply this local compensation in a feedforward scheme where a lookup table contains QFend and QDend settings for each gap setting of the IVU. If hysteresis in the QDend/QFend magnets becomes an problem, measurement of the actual magnetic field in the QDend/QFend magnets (with e.g. a Hall probe) could be used in a feedback scheme to ensure proper local matching.

Such a local focusing change matches the optics of the flanking achromats to the IVU, but it also introduces a phase advance. This phase advance has to be compensated globally in order to prevent a shift of the working point from its desired location. Note that this step is crucial since the nonlinear optics design of the storage ring requires precise control over the working point. Consequently, the global optics compensation has to occur simultaneously with the local matching. The global compensation consists of changing the settings on all QFend and QDend magnets in the ring. MAX-lab Internal Note 20110117 details that this IVU gap change requires a global compensation corresponding to roughly 0.05% tuning on all QDend and a 0.01% tuning on all QFend.

The global compensation achieved by adjusting all QFend and QDend magnets can be operated in a feedforward scheme (using a lookup table specifying the required QFend/QDend adjustements as a function of the ID gaps and settings on all QDend and QFend magnets) or in a feedback scheme where the target is maintaining the working point at a predefined position. The feedforward scheme is non-trivial and error-prone. The feedback scheme on the other hand is less complicated and more robust, it does however require an online tune measurement (for example from turn-by-turn BPM data or from a spectrum analyzer connected to a pair of striplines). In case the tunes cannot be constantly measured without significantly perturbing the beam, we will be forced to adopt a feedforward scheme.

3 Estimate of required synchronization

In order to define synchronicity requirements it is important to recall that the overall required gradient power supply stability is 10^{-4} [4]. We expect gradients to be applied to within their design setting with an rms error less than 10^{-4} at all times. The overall gradient error is further determined by several other error contributions, most importantly the individual mechanical tolerances within theoretically identical magnets in a family. Using this stability level and the setting changes in the example above, we can now proceed to make an estimate of the required synchronization between quadrupole power supplies.

For the local compensation using the QFend and QDend magnets located at the IVU, we see that a change of setting by up to 0.5% is required. Considering that this gap change will occur over a typical time $T = 10$ s, we derive that the time interval τ, within which synchronization between the two magnet power supply settings has to be achieved, is given by

$$\tau = \frac{10\,\mathrm{s}}{0.5\%/10^{-4}} \approx 200\,\mathrm{ms}. \tag{1}$$

Meanwhile the global compensation attempts to restore the design working point. It does so by changing the setting on all QFend and QDend magnets (40 individual power supplies). The QDend/QFend currents are adjusted by as much as 0.05% within the same 10 s interval. This translates to a synchronicity requirement between the 40 involved power supplies of $\tau \approx 2$ s, which is a much more relaxed requirement that the one derived in Eq. 1 for the synchronicity between power supplies performing the local compensation.

Note that if the power supplies controlling the QDend and QFend magnets support master/slave mode, the required synchronization could possibly be achieved in a simpler way. In case the global compensation has to be performed in a feedforward scheme, there needs to be a specific synchronization of the power supplies for magnets performing a local compensation (one power supply for QFend and one for QDend) and the power supplies used for the global compensation (twenty QFend and twenty QDend power supplies). If on the other hand, the global correction is based on a tune feedback, no special synchronization between the local and global compensation is required since it will be provided intrinsically through the tune shift as an instantaneous result of the local compensation.

4 Some afterthoughts on sextupoles and octupoles

If the linear optics are corrected properly, i.e. strong IDs are compensated properly according to the above outline, gap movement should become (almost) transparent to the nonlinear optics. One of the design paradigms of the nonlinear optics in the MAX IV 3 GeV storage ring is that nonlinear corrections are applied locally (distributed dispersion, distributed chromatic sextupoles) and resonance driving terms are canceled within achromats (distributed harmonic sextupoles) without relying on interleaving between different achromats. Hence, if the linear optics are properly matched to the IDs, the nonlinear correction within the achromats should be perturbed only slightly. In this sense the proper linear compensation of ID gap movement makes IDs transparent to the nonlinear optics. In such a situation it will not be necessary to adjust sextupoles or octupoles when users change ID gaps.

In general, octupoles and sextupoles will be adjusted. In commissioning this will occur frequently and later during user operation it is possible that it is desirable to adjust the nonlinear settings during initial accumulation when the storage ring is filled after a shutdown or beam dump. However, once the required level of stored current is reached and the storage ring is operated in regular user top-up mode, there should be no reason for frequent and/or strong adjustments to the sextupole and octupole magnets. The same holds for all the auxiliary windings on the sextupoles and octupoles. Therefore, we presently do not foresee special requirements on synchronicity of the associated power supplies.

References

[1] The MAX IV Detailed Design Report, available at `http://www.maxlab.lu.se/node/1136`

[2] S. C. Leemann, MAX-lab Internal Note 20110117, available at `http://www.maxlab.lu.se/node/999`

[3] M. Eriksson, J. Andersen, private communication.

[4] M. Eriksson, S. C. Leemann, unpublished internal note.