CORRECTION OF THE INFLUENCE OF PERSISTENT CURRENTS IN THE HERA PROTON RING

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Abstract

The persistent currents in the superconducting magnets of the HERA Proton Ring (HERA-p) produce a strong contribution to the sextupole fields at low energies (e.g. 40 to 150 GeV). Thus the decay and the reinduction of persistent currents during the injection of protons and the ramp respectively cause a nonlinear change of chromaticity. Moreover different persistent currents in dipoles and quadrupoles cause nonlinear tune excursions during acceleration. For efficient proton acceleration a correction of tune and chromaticity at low energies is essential. Experience is available on two methods: A closed loop correction, based on on-line measurements of the sextupole field component in the dipole magnets by means of rotating coils. From these measurements correction currents are derived and applied to the sextupole correction coils. In order to reduce the dependence on delicate sextupole field measurements a second method has been tested. It turned out that persistent currents are sufficiently reproducible to base the correction on pre-defined correction currents which are stored in a table. These corrections are subsequently applied to the sextupole magnets at fixed time intervals. Last year this technique was already used successfully for the correction of the tune shift during the ramp.

1. INTRODUCTION

The most detrimental influence of persistent currents comes from the generation of sextupole field components in the superconducting accelerator magnets [1]. At the injection energy of 40 GeV the sextupole field is about a factor of 30 to 50 times too large and must be compensated very precisely. This is done by sextupole correction coils which are mounted on the beam tube surface inside the superconducting dipole magnets.

A measurement of the sextupole field components in the superconducting dipole magnets during injection and at the beginning of the ramp in HERA-p is plotted in Fig. 1. The left part of the curve shows the decay of the sextupole component during injection at 40 GeV according to the decay of the persistent currents after the end of massage of the superconducting magnets. When the ramp is started the persistent currents are re-induced and thus the sextupole field component increases rapidly until the saturation current density in the superconductor is reached. This happens shortly before 70 GeV. At 70 GeV the ramp is stopped temporarily in order to switch to a higher ramp rate. During this break a decay of the sextupole component can again be observed and the re-induction of the persistent currents above 70 GeV is indicated by a small peak.

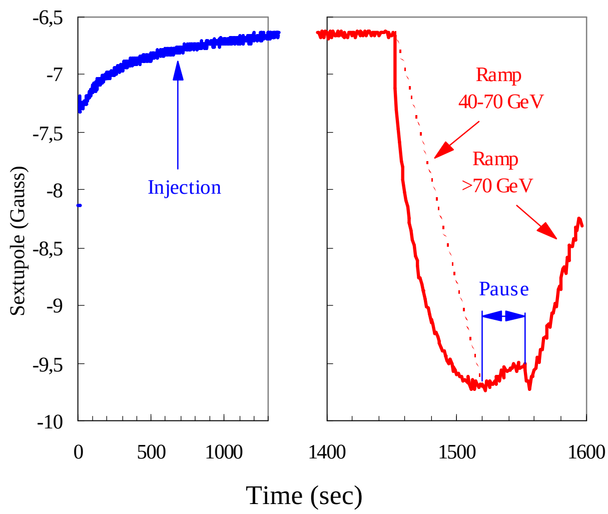

Fig.1: Measured sextupole field component during injection and ramp from 40 to 150 GeV

At energies above 150 GeV the influence of persistent currents on the proton beam can be neglected for three reasons. Firstly the saturation current density decreases rapidly with the increasing dipole field. Secondly the persistent currents are gradually displaced by the main current in the conductor and thirdly the relative contribution of the sextupole component to the main dipole field also decreases.

The ramp of HERA-p is divided into 5 sections where the first two sections cover the energy intervals from 40 to 70 GeV and from 70 to 150 GeV respectively. Within a single section the current of every magnet power supply is changed linearly with a constant ramp rate. However the change of the sextupole component at the beginning of the ramp is strongly nonlinear. In Fig. 1 the nonlinear change of the sextupole component is indicated as the difference of the measured data from the dotted line which connects the data points taken at 40 and 70 GeV. Thus a correction with sextupoles as linear function of beam energy will not prevent a strong change of the chromaticity during the first ramp section. Measurements have shown that with a linear sextupole correction the chromaticity change is still 20 in the horizontal and -30 in the vertical plane and leads to a significant reduction of the proton lifetime during the section of the first ramp [2].

Thus in addition to a linear compensation of chromaticity a nonlinear compensation up to an energy of 150 GeV is necessary. This compensation requires an extra procedure. During the last two years a method has been applied which is based on on-line measurements of the sextupole field component. As another option a new method was developed last year which is based on look-up tables and thus independent of delicate sextupole measurements.

2. SEXTUPOLE CORRECTION BY MEANS OF ON-LINE MEASUREMENTS

The superconducting magnets of HERA have been fabricated by the manufactures ABB and ZANON. For on-line field measurements during normal operation of HERA, reference magnets are provided for the ZANON and ABB family respectively. The reference magnets are connected in series with the other superconducting magnets to a common power supply but do not belong to the beam line of the proton ring. The sextupole field component is measured by means of rotating coils in each reference magnet. The on-line data acquisition is carried out by a VAX-station at the front end. In order to use the measurements for a sextupole correction, serial data transfer is provided to a central NORD cluster which is responsible for the operation of HERA. Here the measured change of the sextupole components is converted to correction currents. Finally the calculated currents are transferred to power supply controllers (PSC) which correct the set point of the power supplies of the sextupole coils.

This sequence is repeated every second and is one of the most delicate procedures during routine operation of the HERA proton ring involving many active components. A large number of components participating in a single procedure implies that the probability of a failure is also large. For this reason a second method of sextupole correction has been developed. This method should serve as a spare routine in case of failure of the procedure described above and is based on look-up tables.

3. SEXTUPOLE CORRECTION BY THE USE OF LOOK-UP TABLES

The goal for the new method is to provide a procedure which is independent of the majority of the components which are needed for the correction based on on-line sextupole field measurements. This goal can be achieved by the use of look-up tables which are directly installed in the PSC of the sextupole correction coils containing pre-defined data to set the correction currents. In this way a procedure can be established which does not depend on all the components preceding the PSC.

The normal task of the PSC is to change the current of a power supply linearly by constant rates until the desired final current is reached. For this purpose clock pulses are sent from the central NORD-cluster to the PSC which change the current by one increment when a pulse has been received. Thus all the PSC of the HERA proton ring are operated simultaneously during the ramp. The operation of a PSC by look-up tables is only slightly different. In this case the rates are looked up by the PSC in pre-defined tables. In the current design of the PSC it is possible to change the rates 32 times within a single section of the ramp thus allowing a nonlinear change of the power supply current as a function of energy.

The increments needed for the sextupole correction are calculated from sextupole measurements which have to be taken once during machine studies before a luminosity run time period starts.

4. TIME DEPENDENCE OF SEXTUPOLE FIELD COMPONENTS DURING INJECTION

The maximum of the sextupole components at 70 GeV is determined by the saturation current density in the conductor of the dipole magnets and thus is always the same for every injection. The value of the sextupole component at the start of the ramp depends, on the other hand, on how long the magnets have waited at 40 GeV during injection [3]. For this reason the change of the sextupole field components on the ramp from 40 to 70 GeV also depends on the duration of injection. This means that the look-up tables have to be parameterisized according to this time. Therefore the PSC which is responsible for the sextupole correction receives one trigger after the end of massage and another when the operator intends to start the ramp. The PSC measures the time between the two triggers and the stored increments in the look-up tables are then scaled according to this time.

5. REPRODUCIBILITY OF SEXTUPOLE FIELD COMPONENTS

A sextupole correction which is based on look-up tables must rely on a good reproducibility of the behavior of the sextupole components. Measurements during commissioning of the superconducting magnets of HERA-p from more than 400 magnets, have shown a consistent behavior among the magnets and were highly reproducible [4]. In addition measurements under normal operating conditions during the last year have led to the same result that the reproducibility is highly sufficient in order to guarantee a successful sextupole correction by look-up tables. However these measurements have shown that the behavior of the sextupole components strongly depends on whether a massage of the superconducting magnets has started from 40 GeV or from 820 GeV. In the first case the transport current in the superconducting dipole magnets is changed from 250 A (which corresponds to a particle energy of 40 GeV) to 5024 A (e.g. 820 GeV) and then is reduced to 50 A before it is finally set back to 250 A. In the second case the massage starts at 5024 A. Both procedures are applied in HERA-p depending on whether the preceding ramp was aborted or was successfully accomplished. Thus the type of massage has to be considered in the look-up tables. As a result of the measurements during the last year the maximum observed deviations of the sextupole component from the average values 5 minutes and 60 minutes after the end of massage are listed in table 1.

Tab.1: maximum observed sextupole deviations during injection

	ZANON (Gauss)	ABB (Gauss)
maximum sextupole deviation 5 minutes after end of massage	0.06 ±0.02	0.10 ±0.02
maximum sextupole deviation 60 minutes after end of massage	0.09 ±0.02	0.11 ±0.02
sextupole deviation related to the average change within the time interval considered above	0.10 ±0.02	0.08 ±0.02

The maximum relative sextupole deviation between 5 minutes and 60 minutes after the end of massage is 0.1 Gauss. According to this result one can say that one has to expect a maximum chromaticity error of ±2.5 due to uncertainties in the reproducibility of the sextupole behavior when operating with look-up tables. The average chromaticity error however will be only ±0.5.

6. TUNE CONTROL BY LOOK-UP TABLES

The tune during the ramp of HERA-p is controlled already with great success by look-up tables, using a method very similar to that described above.. The effect of the tune correction by this method is demonstrated in figure 2. As an example, figure 2 shows the tune deviation during the ramp section from 300 GeV to 677 GeV with and without a tune correction.

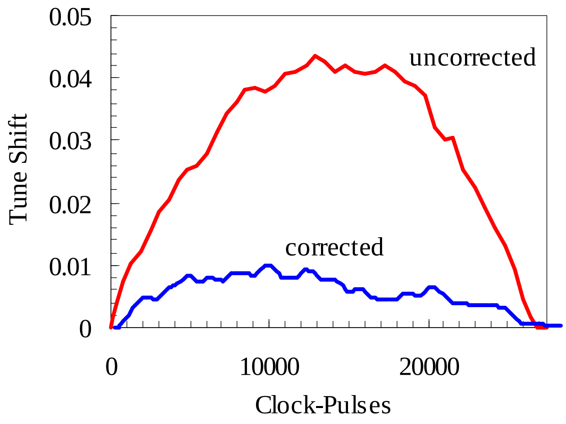

Fig. 2: Plot of the uncorrected and corrected tune shift using look-up tables for the energy range from 300 to 677 GeV

7. STATUS OF THE DEVELOPMENT

The encouraging results from the tune correction by look up-tables gave the final impulse for a similar development to correct the sextupole components. In the last year the PSC of the sextupole correction coils were modified for the operation with look-up tables and software was developed to generate the look-up tables from sextupole field measurements. Finally a single test of the new procedure was possible during machine studies last December which proved that the new procedure is operates correctly. This year it is planned to continue testing and finally to enable a routine use of the new method.

REFERENCES

[1] B. Holzer, Impact of Persistent Currents on Accelerator Performance, Particle Accelerators (1996), (in press).

[2] O. Meinke, Measurement and Control of Q-Values and Chromaticity in the HERA-Proton Ring (original Title in German), Diploma Thesis, DESY-HERA **92-08** (1992).

[3] H. Brück et al, Time Dependence of Persistent Current Field Distorsions in the Superconducting HERA Magnets, in: *Proeedings of the European Particle Accelerator Conference* (Nice, France 1990).

[4] P. Schmüser, R. Meinke, Y. Zao, Methods of Harmonic Measurements in the Super- conducting HERA Magnets and Analysis of Systematic Errors, DESY-HERA **91-13** (1991).