Measurement of Slow Closed–Orbit Motion in the HERA Electron Ring in Correlation with Ground Motion

W. Decking[1], K. Flöttmann[1] , J. Rossbach,
Deutsches Elektronen–Synchrotron, Hamburg, FRG

Abstract

The closed–orbit motion of the HERA electron ring has been recorded with high precision for periods of up to 80 seconds. Simultaneously, ground motion in the HERA tunnel has been detected. Numerical correlation analysis is discussed. Results are in agreement with numerical and analytical model calculations and suggest the conclusion that the closed–orbit motion in the 1 ... 100 Hz regime is dominated by mechanical motion of quadrupole magnets.

1 Introduction

There are three main reasons for the increasing importance of ground motion investigations for particle accelerators, namely:

a) Due to the large size of many accelerator projects currently under construction or consideration, the cumulative effect of microscopic quadrupole motion may result in macroscopic beam orbit motion [1,2,3]

b) Beam stability requirements of synchrotron radiation users increase continually because of more sophisticated experimentation techniques [4].

c) Most future colliding beam facilities will involve individual magnet optics systems for each beam species (e.g. HERA, LHC, SSC, Linear Colliders). This is in contrast to the overwhelming majority of existing machines, where beam separation at the interaction point is excluded in principle, because particles and antiparticles share a common magnet system.

In order to estimate the impact of ground motion on HERA performance, ground motion as well as quadrupole magnet motion has been measured in the HERA tunnel [2]. Measurement of the superconducting quadrupole magnet's motion is a special task and will be described in a separated paper [5].
As far as elastic ground deformation is concerned, model calculations show that ground wave frequencies < 1 Hz do not affect the HERA closed orbits [2]. Much slower localized ground deformations however might (and do) occur and cause considerable orbit drifts (see results below and [9]). We nonetheless focus on fast ground motion $\nu > 1$ Hz in the present paper, because its effect on the closed orbits is much harder to detect and to compensate. This motion, while fast from the geological point of view, is still slow (in most cases but not in all! even adiabatic) with respect to beam dynamics. Calling it "slow closed–orbit motion due to fast ground motion" might be most appropriate.

[1] II. Inst. für Experimentalphysik der Universität Hamburg

2 Instrumentation

Ground motion was detected by a portable seismometer with output voltage proportional to ground velocity. For magnet motion measurement, much smaller accelerometers (Brüel & Kjaer, Type 4379S) are more suitable. Minimum operation frequency of both devices is about 1 Hz.
A widely used technique for observing the motion of the electron beam orbit is to monitor the direction of the synchrotron radiation fan emerging from a bending magnet [10,11,12] Although resolution of orbit motion well below the 1 μm level has been demonstrated [9], we nevertheless prefer observation by the standard HERA beam position pick-up buttons [13,14] for several reasons:

a) Orbit stability is most important around the interaction regions. Extraction of synchrotron radiation beams would be very complicated in this area.

b) We have as many as 274 pick–up monitors in HERA, anyway, but no long synchrotron radiation beam line.

c) High precision alternatives to synchrotron radiation observation are of general interest for devices like proton and heavy ion rings and linear colliders.

The electron beam position is determined by the pick–up monitors turn by turn. Resolution is limited to 30 μm by ADC resolution and amplifier noise if turn by turn measurement is considered. However, it can be enhanced considerably by averaging over many turns. This is done by a microprocessor device, which is also capable of storing up to 7000 of those average values [15]. As an example, Fig. 1 shows the closed–orbit motion at the pick–up station WR 205. Time resolution is 10 ms, i.e. the plot displays 2000 position values both in horizontal and vertical position, each of which is the result of averaging over 473 turn by turn measurements (47317 Hz is the revolution frequency in HERA).

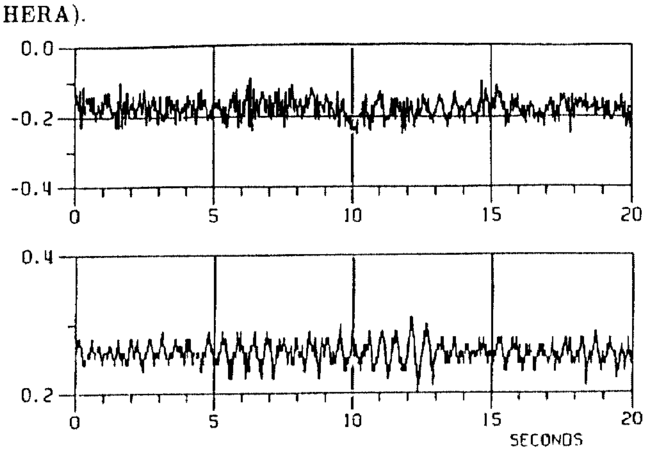

Figure 1: Closed–orbit motion in the HERA electron ring as measured by pick–up buttons at 10.22 a.m. on Wed., 27/9/89. Resolution is arbitrarily limited to 10 μm. Approx. 10^{10} electrons have been stored at 13 GeV. Beta– functions at the pick–up position are $\beta_x = 27\ m$, $\beta_y = 59\ m$.

3 Experimental Results

At least during daytime, the motion of the HERA tunnel is dominated by cultural noise. This is illustrated by Fig. 2, which shows a long term record of the vertical rms tunnel motion during one week. Only frequency components above 1 Hz are considered. Rms-values have been calculated for time intervals of 1 minute. Peak to peak values are larger by a factor of 7. The

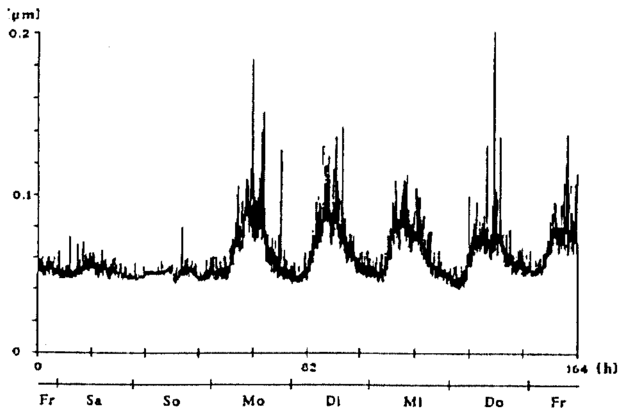

Figure 2: Long-term record of the rms HERA tunnel motion (vertical) from 15/9/89 till 22/9/89.

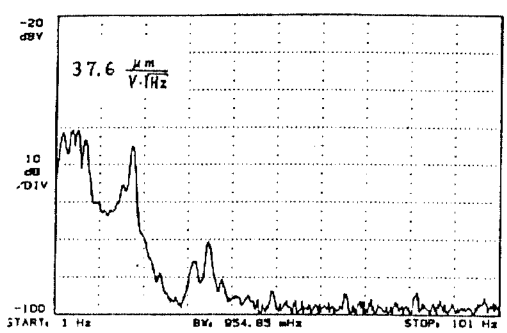

Figure 3: Typical spectrum of vertical quadrupole displacement at the HERA electron ring

motion of quadrupole magnets is, of course, more relevant for closed orbit distortions. A typical spectrum between 1 Hz and 101 Hz is shown in Fig. 3 for an electron ring quadrupole. It is dominated by mechanical eigenmodes of the magnet supports except for the 2 Hz component, which is already prominent in the ground motion spectrum. For the 2 – 5 Hz components it has been proven experimentally that they partially stem from plane ground waves crossing the HERA site from NE direction. Using phase correlation technique, the phase velocity has been determined at $(240 \pm 40) m/s$. Best guess for Rayleigh wave velocity c_R from the literature is in good agreement:

$$c_R = 0.92 \cdot c_S = 230\ m/s$$

(using $c_S = 250\ m/s$ for sand with gravel [16]).

Since the betatron wavelength of the HERA electron ring is about 140 m, the plane wave model predicts considerable closed orbit response to plane wave frequencies above [2,4,6]

$$240 \frac{m}{s} \ /\ 140\ m = 1.7\ Hz.$$

This means that all quadrupole motion components in the 2 – 5 Hz region have a high potential to contribute considerably to the beam motion spectrum. This sensitivity to quite low frequency ground waves (with comparatively large amplitudes in general) is a detrimental feature of all large storage rings. For comparison, the Photon Factory at KEK is insensitive to vibration frequencies below 10 Hz [10,17].
It should be noted that there are many different types of magnet supports in the HERA electron ring. They all have slightly different eigenmodes. The gross behaviour, however, is similar to that displayed in Fig. 3. Consequently we only assume some overall phase correlation between the quadrupoles' motion for the 2 – 5 Hz components, i.e. all the other frequency components will only contribute to the orbit distortion in an uncorrelated way.

In Fig. 4 we present the spectrum of the vertical closed orbit motion. The major contribution is in the 2–5 Hz region, exactly as in the quadrupole motion spectrum. The 2 Hz component is especially pronounced, as expected. Remember, that the corresponding ground wavelength equals the betatron wavelength.

We conclude that the closed-orbit motion above 1 Hz is essentially caused by mechanical motion of quadrupole magnets.

There is also a considerable slow orbit drift, mainly in the horizontal plane, which is illustrated in Fig. 5. Whether this is due to mechanical or electrical instability is much harder to decide. It requires micrometer measurement of very low frequency motion, which is a hard task.

Finally we have determined the energy dependence of the orbit motion. One predicts 1/E behaviour for beam motion due to power supply noise and no energy dependence in case of mechanical motion. Figure 7 includes beam position data from different pick-up stations as well as (1/E + const.) fits for rms and peak to-peak values. Fit results are as follows:

$$fit\ equation: \qquad y = \frac{a}{E/GeV} + b$$

quantity	correlation coefficient of linear fit	a±Δa	b±Δb
rms beam motion	0.75	0.0063±0.0057	0.0014±0.0004
peak – peak	0.58	0.042±0.050	0.0075±0.0038

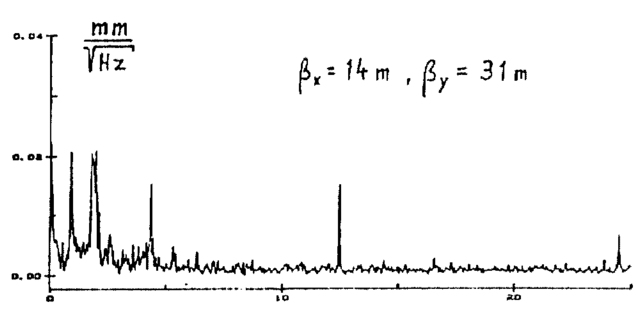

Figure 4: Spectrum of the vertical closed orbit motion in the HERA electron ring.

The 1/E contribution is obviously very small. This again confirms our interpretation that — at least at luminosity energy of 26 GeV — the orbit motion is due to magnet motion.

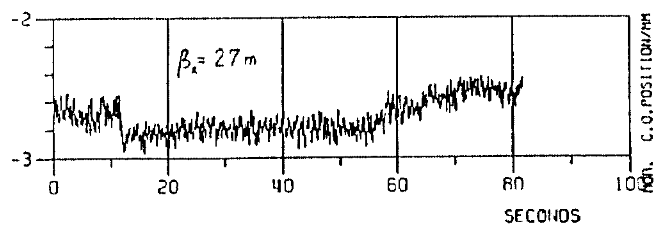

Figure 5: Another record of horizontal closed orbit motion. In this case a sudden jump and slow drift are superimposed on the permanent noise. The peak-to-peak motion during this 80 s period corresponds to 0.5 σ_x of the electron beam size.

4 Conclusions

Using pick up electrodes and averaging techniques, slow closed orbit motion is measurable with resolution below the 10 μm level. For the HERA electron ring we found that the major reason for orbit motion in the 1 . . . 100 Hz regime is mechanical motion of quadrupole magnets. This conclusion is motivated by three observations:

a) The spectra of orbit motion and magnet motion are similar.

b) The orbit motion is nearly independent of beam energy.

c) The magnitude of orbit motion fits well with the value predicted from ground motion measurements and orbit response theory.

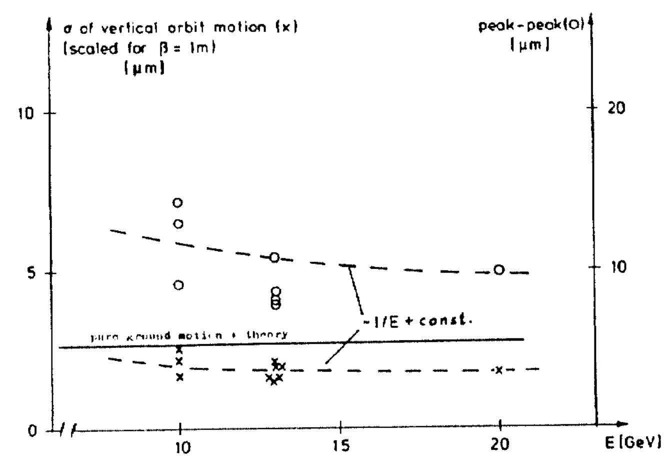

Figure 6: Energy dependence of vertical closed orbit motion in HERA (circles: peak to peak, crosses: rms-values). All measurements taken at different pick-up stations have been normalized for $\beta_x = 1$ m. The solid line is the theoretically predicted rms value using magnet motion data.

We estimate the horizontal and vertical separation of the HERA electron and proton beams at not much more than one tenth of the respective beam sizes. The effect on the luminosity being negligible, this small, time-dependent separation might nevertheless injure proton lifetime severely [7,8].

4.1 Acknowledgements

The authors are indebted to R. Brinkmann, J. Klute, S. Paetzold and M. Werner for valuable advice and assistance.

References

[1] G.E. Fischer, P. Morton, SLAC PUB 3870, 1986

[2] J. Rossbach, DESY 89-023, 1989

[3] G.E. Fischer, SLAC PUB 5024, 1989

[4] T. Aniel, J.L. Laclare, LNS/086, 1985

[5] W. Decking, K. Flöttmann, this conference

[6] J. Rossbach, Part.Acc., Vol. 23, 121 - 132, 1988

[7] M. Cornacchia, L. Evans
Part. Acc., Vol. 19, 125 - 144, 1986

[8] R. Brinkmann, DESY HERA 89-24, 1989

[9] T. Katsura, Y. Kamiya, K. Haga, T. Mitsuhashi
(QCD 183 : P3 : 1987)

[10] T. Katsura et al., H.E. Acc., Novosibirsk, 1989

[11] W. Brefeld, Nucl. Instr. Meth., A 261, 1987

[12] W. Brefeld, not published

[13] V. Commichau et al., DESY HERA 81-04, 1981

[14] H. Frese, G. Hochweller, F. Peters, K. Wille
IEEE Trans. NS, Vol. NS 24, No 3, 1977

[15] R. Neumann, M. Werner, private communication

[16] D.D. Barkan
Dynamics of Bases and Foundations p. 347

[17] K. Huke, Japan J. Appl. Physics, 1986