A MECHANICAL FEEDBACK SYSTEM FOR LINEAR COLLIDERS TO COMPENSATE FAST MAGNET MOTION

C. Montag, J. Rossbach
DESY
Notkestrasse 85
D-22603 Hamburg

Abstract

For high luminosity, all linear collider schemes under study require very low emittance beams. When transverse beam dimensions of the opposing linacs become very small, high beam position stability is necessary to maintain high luminosity. For the 500 GeV c. m. S-band collider SBLC uncorrelated rms quadrupole vibrations must be smaller than some 70 nm and have to be reduced to 20 nm for the 1 TeV upgrade.
An inexpensive mechanical stabilization scheme based on geophones, piezocrystals and a digital feedback system has been successfully tested. It damps quadrupole motions in a frequency range of $2 - 30$ Hz by factors up to 4, such that remaining magnet motions may be within tolerance limits. Based on a geophone with noise level below 1 nm, it is likely that this system may allow stabilization below the 10 nm level.

I. INTRODUCTION

To achieve a luminosity at least comparable to existing e^+e^- storage rings like LEP, all linear collider schemes currently under study require very low emittance beams focused to transverse beam dimensions of some 10 nm vertical and some 100 nm horizontal.
Since luminosity degradation should not exceed 3%, which corresponds to beam center positions being 0.25σ off center, tolerable quadrupole jitter amplitudes are limited to [1]

$$\sigma_q = 0.25 \cdot \sqrt{\frac{\epsilon_{\text{end}} \cdot \overline{\beta}_{\text{end}}}{N_{\text{quads}}}} \cdot \cos\frac{\mu}{2}, \tag{1}$$

where ϵ_{end}, $\overline{\beta}_{\text{end}}$ and N_{quads} are the actual emittance at the end of the linac, the beta function averaged over the last FODO cell and the number of quadrupoles, respectively. μ is the phase advance per cell. It can be shown that eq. 1 also holds if the beta function is scaled according to $\beta \propto \gamma^\alpha$ with arbitrary α between 0 and 0.8 [2].
Using SBLC parameters [3], this leads to $\sigma_q = 70$ nm and $\sigma_q = 20$ nm for the 500 GeV and the 1 TeV machine, respectively. Comparison with measured ground motion of HERA Hall West (see fig. 1) [4] shows that these limits are exceeded by ground motion amplitudes at frequencies below 6 Hz (20 nm limit) and 0.2 Hz (70 nm limit).

II. COMPENSATION SCHEMES

For ground motion compensation considerations, the frequency spectrum of this disturbance can be divided into two

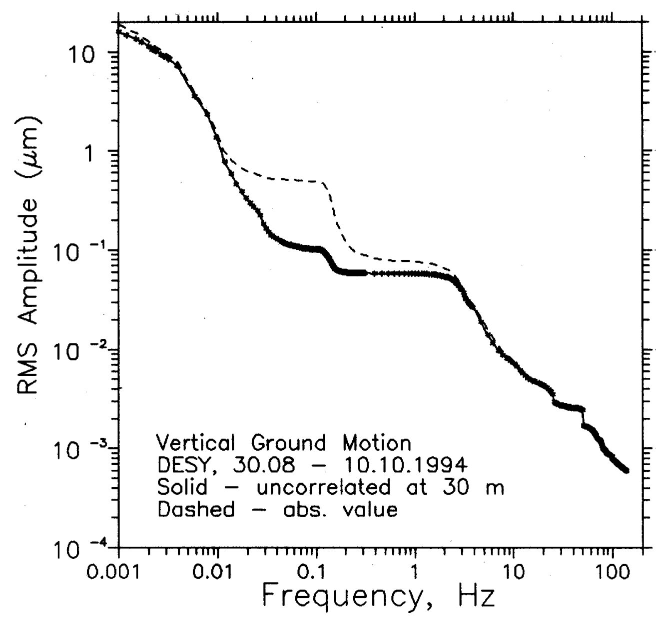

Figure. 1. rms values of ground motion measured in HERA Hall West

parts, each of them requiring different compensation techniques. Due to the quite low repetition rate f_{rep} of nearly all linear colliders, beam based orbit correction schemes are applicable only to compensate very slow ground motion with frequencies not exceeding $0.05 \cdot f_{\text{rep}}$. For the SBLC with $f_{\text{rep}} = 50$ Hz, this leads to an upper limiting frequency for the application of beam based correction schemes of approximately 2 Hz. Therefore, ground motion with frequencies beyond this limit requires a different technique.
The simplest considerable attempt consists of some kind of "spring", acting as passively damping quadrupole support due to the $1/f^2$ characteristics for frequencies higher than the resonance frequency of the spring. To be able to damp frequencies as low as 2 Hz, a resonance frequency of some 1 Hz is required. This leads to a spring compression due to the magnet mass of 25 cm, which is unacceptable because of the high compliance of such a system. Therefore, passive damping is feasible only in the high frequency region ($f > 100$ Hz).
To compensate fast ground motion in the frequency band 2 Hz – 100 Hz, an active stabilization scheme consisting of a geophone measuring the velocity of the magnet motion on top of each quadrupole and a piezoelectric actuator tilting the magnet around its horizontal transverse axis in order to keep its center at rest has been built (figs. 2, 3).

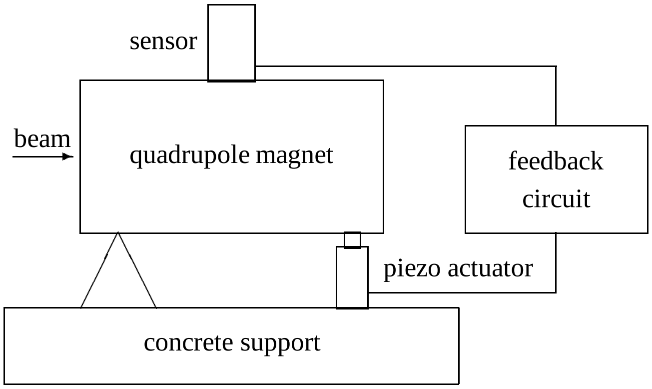

Figure. 2. Schematic view of feedback system to compensate fast ground motion.

The internal noise of these sensors was obtained by measuring the output signals of two sensors responding to the same input signal (ground motion). Both signals were integrated in order to get the displacement. The averaged noise power spectrum $\overline{\Phi}_{nn}$ can then be calculated as

$$\overline{\Phi}_{nn} = \overline{\Phi}_{yy} - |H|^2 \overline{\Phi}_{xx}, \tag{2}$$

where $\overline{\Phi}_{xx}$ and $\overline{\Phi}_{yy}$ are the averaged power spectra of the two displacement signals $x(t)$ and $y(t)$, respectively. Note that here and in the following both x and y describe vertical motion. H is the ratio of the transfer functions of the two geophones. In our case of two identical sensors, it is assumed to be unity. For more details, see [5].
The internal noise σ_n^2 in the frequency band from a lower frequency f_0 to infinity can the be calculated by integrating the noise power spectrum over this frequency range:

$$\sigma_n^2(f_0) = \int_{\omega_0 = 2\pi \cdot f_0}^{\infty} \overline{\Phi}_{nn}(\omega) d\omega. \tag{3}$$

Fig. 4 shows the measured rms noise level $\sigma_n(f_0)$ of this sensor type in the frequency band f_0 to infinity as a function of the lower frequency f_0. As can be seen, the noise level in the frequency band above 2 Hz corresponds to approximately 1 nm.

III. RESULTS

The system described in section II has been successfully tested. With one sensor on the floor below the magnet support and the other on top of the magnet, motion signals have been obtained using a PC with 12 bit A/D board. These signals where integrated in order to get the displacement and Fourier transformed to get the power spectra Φ_{xx} and Φ_{yy}. From these power spectra, the rms value of the displacement in the frequency band from a lower frequency f_0 to infinity was calculated by integration over this frequency band:

$$\sigma_x^2(f_0) = \int_{\omega_0 = 2\pi \cdot f_0}^{\infty} \Phi_{xx}(\omega) d\omega. \tag{4}$$

Fig. 5 shows simultaneously measured rms values $\sigma_x(f_0)$ and $\sigma_y(f_0)$ of vertical motion on the floor (solid line, σ_x) and on

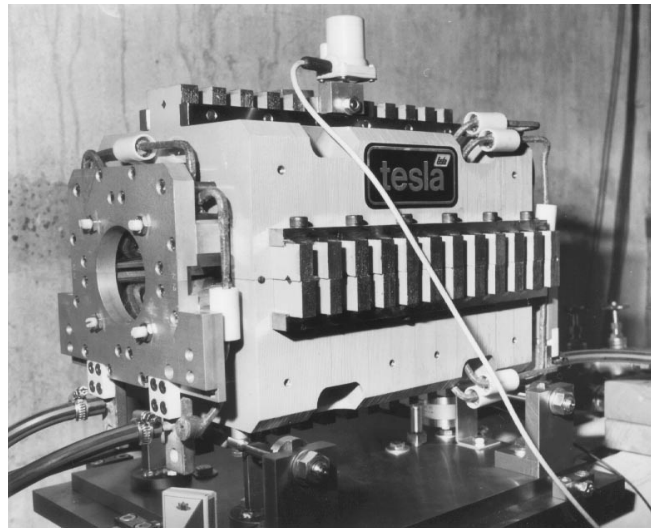

Figure. 3. Active stabilization system, consisting of a geophone on top of the quadrupole and a piezo driver to tilt the magnet.

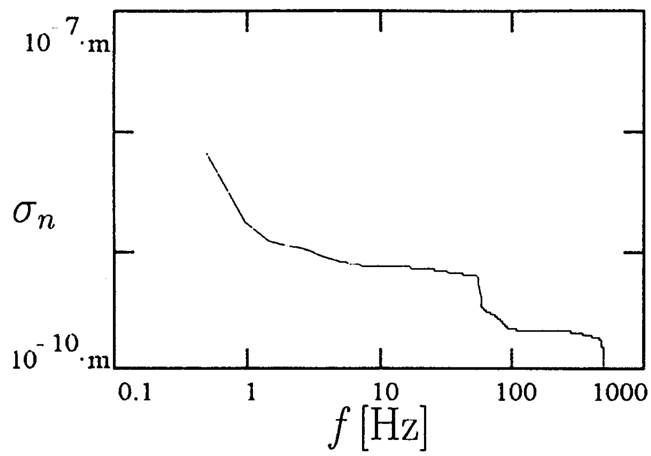

Figure. 4. rms value σ_n of the internal noise of the geophone in the frequency band f_0 to infinity as function of the lower frequency f_0.

top of the magnet (dashed line, σ_y) as function of the lower frequency f_0.
These data were obtained under very noisy conditions in DESY hall 2, with a cooling water flow of 220 l/h (design value: 120 l/h). Fig. 6 shows the measured feedback gain of the system, calculated from the square root of the ratio of the power spectra simultaneously measured on the floor and on top of the magnet.

IV. CONCLUSION

It has been successfully demonstrated that active stabilization of mechanical quadrupole vibrations to levels necessary for linear collider operation is feasible even in noisy environments. For the whole linear collider, the costs of these ground motion compensation devices would not exceed 10 Mio US-$. Therefore, fast ground motion considerations should not dominate the choice of the linear collider site.

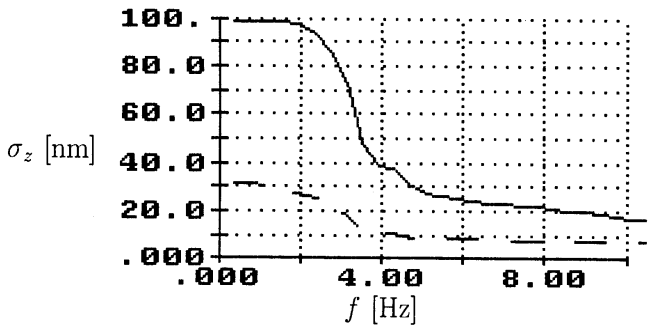

Figure. 5. rms values of motion signals in the frequency band f_0 to infinity as function of the lower frequency f_0, simultaneously measured on the floor below the magnet (solid line) and on top of the quadrupole (dashed line).

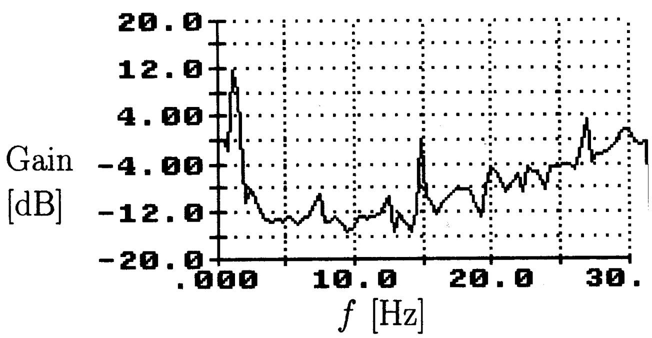

Figure. 6. Measured feedback gain of the active stabilization system.

V. ACKNOWLEDGEMENTS

We would like to thank G. Meyer and H. Kaiser for the excellent design of the magnet support and many helpful discussions.

References

[1] T. O. Raubenheimer, SLAC report 387, 1991

[2] J. Rossbach, Tolerance on uncorrelated Motion of Quadrupoles for Linear Colliders, DESY M/VM 93-01

[3] N. Holtkamp et al., Status of the S-Band Linear Collider Study, DESY M-93-05

[4] V. Shiltsev, B. Baklakov, P. Lebedev, C. Montag, J. Rossbach, Measurements of Uncorrelated Ground Motion at HERA, these proceedings

[5] C. Montag, M. Lomperski, J. Rossbach, Studies of Measurement and Compensation Techniques of Magnet Motion for Linear Colliders, Proc. EPAC 94