AN ACTIVE MECHANICAL STABILIZATION SYSTEM FOR LINEAR COLLIDER QUADRUPOLES TO COMPENSATE FAST GROUND MOTION

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Abstract

Next generation Linear Colliders require very low emittance beams in order to achieve sufficiently high luminosities. Due to the extremely small beam sizes of some ten nanometers height at the IP, these machines are very sensitive to ground motion leading to uncorrelated quadrupole jitter. As measurements performed at several laboratories indicate, the required vertical jitter tolerances of 30 nm rms for frequencies above ≈ 2 Hz cannot be guaranteed in an active accelerator environment. Therefore, an active stabilization system based on geophones and piezo actuators has been developed as part of the DESY S-band Linear Collider Test Facility. This system damps magnet motion in the frequency band $2-30$ Hz by up to -14 dB, resulting in remaining jitter rms values of some 25 nm even in a very noisy environment. Recent results of the system's performance with different sensor types will be presented.

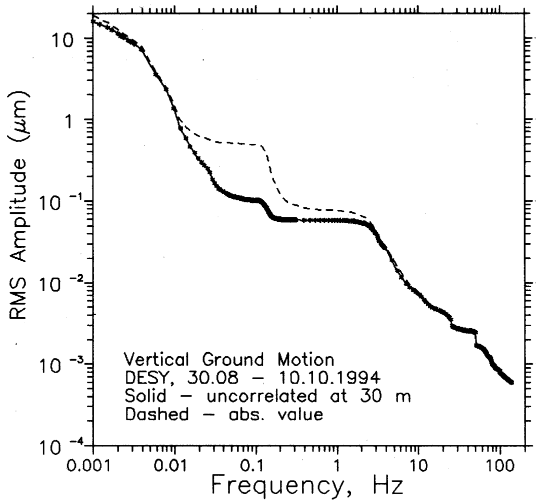

Figure 1: Integrated power spectrum of vertical ground motion obtained in HERA hall west.

Introduction

To achieve sufficiently high luminosities of some $10^{33}\,\mathrm{cm}^{-2}\mathrm{sec}^{-1}$, future linear colliders make use of extremely tiny beam spot sizes at the interaction point (IP) of some 10 nm height and some 100 nm width.

To provide head-on collisions of the two opponing linac beams, beam trajectories have to be controlled by some means in order to fight ground motion induced beam jitter. The required tolerances for uncorrelated vertical quadrupole vibrations can be estimated as [1, 2] 85 nm vertically and 380 nm horizontally.

Since ground motion measurements (fig. 1) at DESY [3] indicate that vertical ground motion amplitudes have to be expected in the vicinity of the required tolerance limit, an active stabilization system for the linac quadrupoles has been developed to fight beam jitter at its source. This paper describes some considerations leading to the present design of the system as well as some results of active stabilization. Additionally, possible further improvements of the system's performance using broadband seismometers are presented.

Design considerations

For compensation purposes, the spectrum of ground motion can be divided into two frequency bands, each of them requiring different compensation schemes.

While for low frequency distortions beam-based methods are applicable, this method fails in the high frequency region beyond $f_{\mathrm{rep}}/6$ and leads to reasonable damping only below approximately $f_{\mathrm{rep}}/25$ [4]. Therefore, high frequency beam jitter has to be compensated independently of the beam.

The simplest possible solution consists of a passive vibration absorber with resonance frequency f_r well below the lowest frequency to be compensated. Though such a system would be capable of damping high frequency vibrations by a factor $1/\omega^2$, it would, on the other hand, be very sensitive to any excitation acting on the magnet itself, like cooling water pressure fluctuations etc.

To achieve significant damping of frequencies beyond 2 Hz, a resonance frequency of $f_r = 1$ Hz is necessary. Together with a magnet mass of 100 kg, this leads to a very small spring constant of the passive absorber being $D = 4000\,\mathrm{N}\cdot\mathrm{m}^{-1}$. Therefore, even a static force as small as $4\cdot 10^{-3}$ N would lead to a magnet displacement of $1\,\mu$m.

These considerations led to the development of an active stabilization system with a vibration sensor on top of each magnet and some means of actuator to move the magnet in order to keep it at rest.

As can be easily shown, application of an active feedback system to a low frequency passive vibration absorber would lead to a modification of the system's spring constant only within the limited bandwidth of the vibration sensor, while for very low as well as very high frequencies the system would show the same behaviour as a purely passive one [5]. Therefore, piezo actuators with high resonance frequencies have been chosen.

At present state, geophone type vibration sensors made by KEBE Scientific Instruments are used to measure magnet motion. The internal noise of these sensors has been determined to 1.1 ± 0.3 nm for frequencies higher than 2 Hz [6], which is well below the desired remaining magnet jitter.

For simplicity reasons, the mechanical design was chosen such that the magnet is tilted by a single piezo actuator around its horizontal transverse axis, as schematically shown in figure 2.

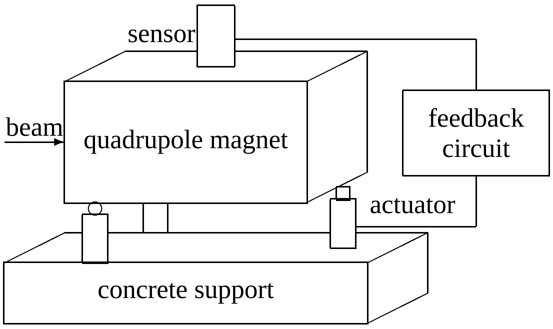

Figure 2: Schematic view of the active stabilization system.

The complete active stabilization system is shown in figure 3.

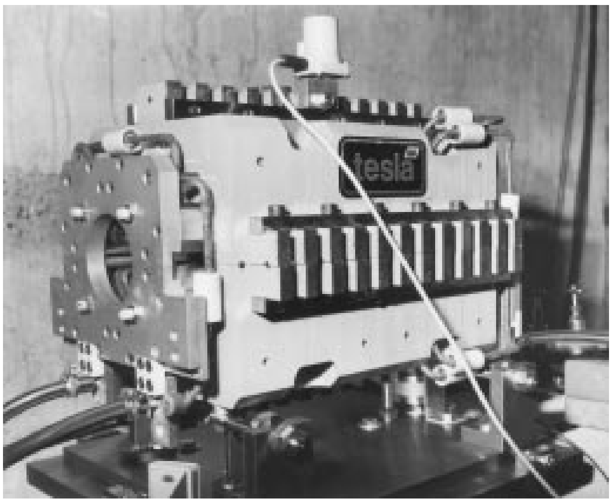

Figure 3: Active stabilization system, consisting of a KEBE geophone on top of the magnet and a piezo actuator below it to tilt the quadrupole around its horizontal transverse axis. A match-box in front indicates the size.

Experimental results

The active stabilization systm has been set up in DESY hall 2, an experimental hall close to the DESY synchrotrons. Due to the vicinity of two accelerators, several transformers and other technical equipment, this can be considered as a typical example for an operating Linear Collider environment. Therefore, the results obtained there should be similar to those to be expected in the future accelerator.

To determine the system's performance, a second identical sensor was placed on the floor just below the magnet. The signals of both the feedback sensor and this second one were sampled simultaneously at 400 Hz. The transfer function of the active stabilization was calculated as the square root of the ratio of the two corresponding power spectra Φ_{xx} and Φ_{yy}. The resulting transfer function is shown in figure 4, together with the theoretically expected curve..

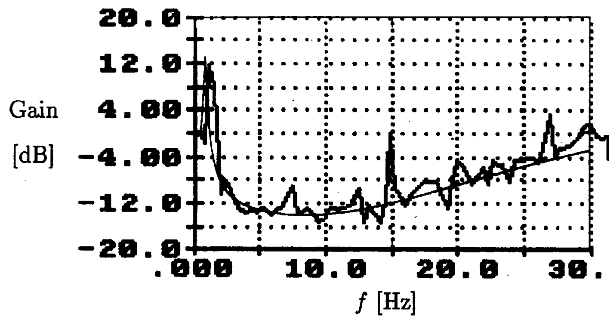

Figure 4: Mesured feedback gain (thick line) in the frequency band from 0 to 30 Hz, calculated from the square root of the ratio of the power spectra measured on top of the magnet and on the ground, respectively. The smooth thinner curve shows the theoretical transfer function.

Additionally, the rms values σ_x and σ_y of the displacement in the frequency band f_0 to infinity were calculated as

$$\sigma(f > f_0) = \sqrt{\int_{f_0}^{\infty} \Phi(f)\,\mathrm{d}f}. \tag{1}$$

The result is shown in figure 5.

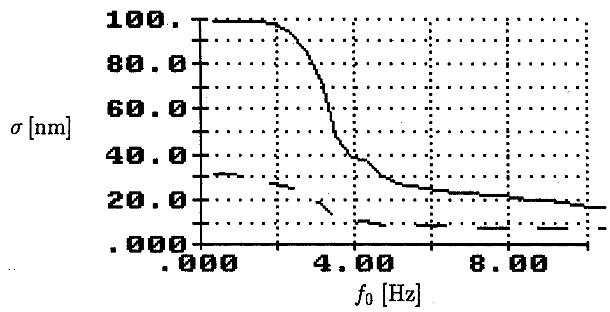

Figure 5: Measured rms values of ground (solid) and magnet motion (dashed0 with the feedback system switched on in the frequency band f_0 to infinity as function of the lower frequency f_0, f_0 ranging from 0 to 10 Hz.

Future improvements

To improve the system's performance, the application of broadband seismometers made by Guralp Systems Ltd. is under study. These sensors provide flat velocity response in the frequency band from 0.1 to 50 Hz. Therefore, an increased feedback gain around 2 Hz is expected. Figure 6 shows a comparison of the theoretical transfer functions of the existing system with KEBE geophones and the device under construction with these new seismometers.

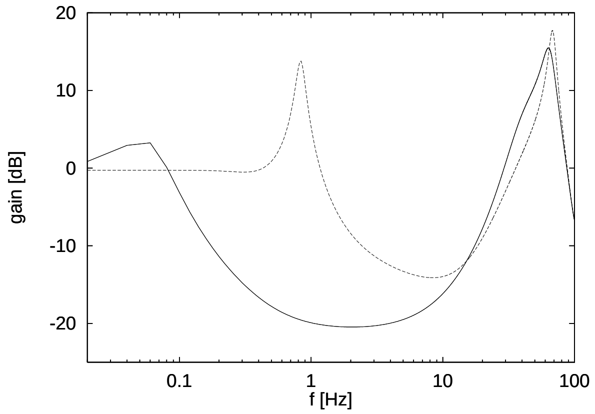

Figure 6: Comparison of theoretically calculated transfer functions of the present system with KEBE geophone (dashed) and the new design with Guralp broadband seismometer (solid).

Using these transfer functions $|H(f)|$ and the ground motion power spectrum $\Phi(f)$ measured in HERA hall West, the expected rms value σ can be calculated as

$$\sigma(f > f_0) = \sqrt{\int_{f_0}^{\infty} |H(f)|^2 \cdot \Phi(f)\,\mathrm{d}f}. \qquad (2)$$

Figure 7 shows the corresponding rms values of ground and magnet motion using the transfer functions of the two systems.

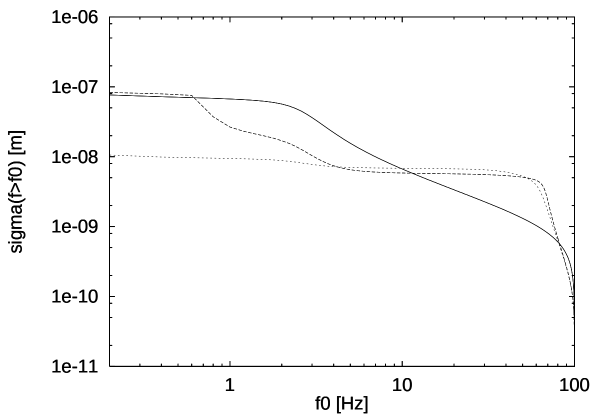

Figure 7: Theoretical rms values for the present system with KEBE geophone (dashed) and the new design with Guralp broadband seismometer (dotted), calculated from the ground motion spectrum measured in HERA hall West and the transfer functions shown in fig. 6. The solid line represents the ground motion rms value.

Conclusion

As has been experimentally demonstrated, active stabilizatio of mechanical quadrupole vibrations is possible down to some 25 nm rms for frequencies beyond 2 Hz, which is well below the required tolerance for the SBLC main linac. With new broadband seismometers used as feedback sensors, even the much tighter tolerances in the final focus system might be met, at least under the presupposition of a less noisy environment due to the absence of accelerating structures, modulators, klystrons etc.

References

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