Measurement of the Motion of Superconducting Quadrupole Magnets at Liquid Helium Temperatures

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Abstract

For thermal isolation purposes the superconducting coils of the magnets in the HERA proton accelerator have been suspended from the cryostat wall with glass fibre strips. Since quadrupole motion induces beam motion, it is important to examine the mechanical properties of the quadrupole suspension structure. We describe a method to measure the mechanical oscillations of a coil inside the cryostat at liquid helium temperature. Experimental results for different settings of external noise sources (e.g. Helium flux, vacuum pumps) are given and discussed.

1 Introduction

In most of the existing storage rings particles and antiparticles share a common magnet system, so that a beam separation at the interaction point is excluded in principle. HERA as well as other accelerator projects currently being planned (e.g. LHC, SSC) consists of two individual magnet optics systems so that a beam separation can arise. Since quadrupole motion induces orbit motion, one has to investigate quadrupole motion.

2 Instrumentation

For the measurements of mechanical vibrations at the inner part of the HERA proton quadrupole piezoelectric accelerometers (Brüel & Kjaer, Type 4379S) were used. They are small enough to be built into the cryostat.

The output signals of the accelerometers were amplified by sensitive charge amplifiers, which also enable a single or double integration of the signal to get a velocity or displacement proportional signal, respectively. Further signal processing was carried out by a 4-channel Fourier transformer. Figure 1 shows the construction of the accelerometers used.

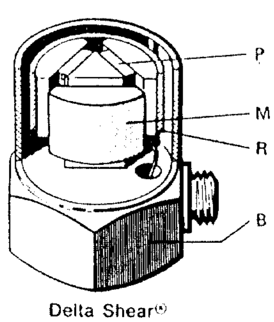

Fig. 1: Accelerometer; M = Seismic Mass, P = Piezoelectric Element, R = Clamping Ring and B = Base [1]

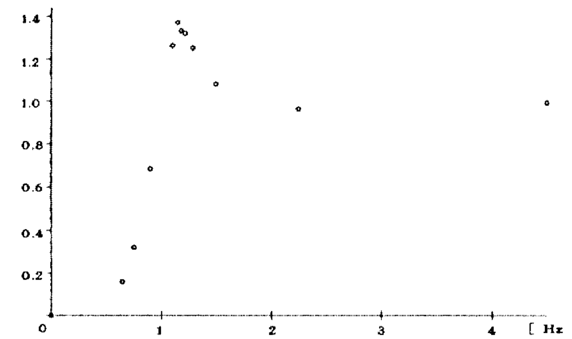

Fig. 2: Transfer function of the charge amplifier in the "displacement" mode

If the accelerometer is moved into vertical direction, the three seismic masses exert shearing forces on the piezoelectric elements whereby charges are set free. The generated charge typically is of the order of 10^{-14} C so that problems with signal-to-noise ratio may arise, especially in the low frequency range.

In Fig. 2 the absolute value of the measured transfer function of the amplifier in the "displacement" mode (double integration) is shown. It is mulitplied by ω^2 and normalized to one in the region where it is constant.

Frequencies well below 1 Hz are suppressed but frequencies close to 1 Hz are amplified by a factor of 1.4 at the maximum. For the measurement of the noise the input of the amplifier was loaded by a capacity of 1 nF, which substitutes the accelerometer and cable.

Figure 3 shows the output noise of the amplifier in the "displacement" mode. At frequencies above 1 Hz it is proportional to $1/\omega^3$. This part is dominated by noise from the capacity or accelerometer, respectively, which is three times integrated, because there is one integrator in the input amplifier to derive a current or voltage signal from the charge signal and two integrations are needed to get a signal proportional to displacement. Therefore the accelerometer itself is an essential source of noise at low frequencies. This is important for measurements at liquid helium temperature, because this noise decreases if the accelerometer is cooled down.

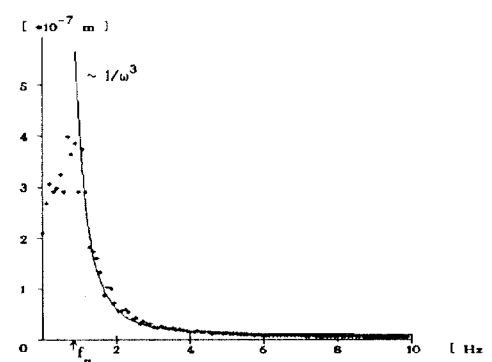

Fig. 3: Noise in the "displacement" mode with a capacity loaded input

3 Calibration at Liquid Helium Temperature

For the calibration of the accelerometer the set-up sketched in Fig. 4 was used. The stainless steel pipe was suspended in the cryostat, so that the lower part with an accelerometer in it dipped into liquid helium. A second accelerometer was placed on the upper warm end of the evacuated pipe.

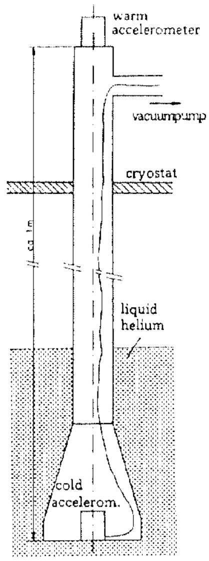

Fig. 4: Calibration set-up

For the calibration measurements, the irregular ground motion noise of the environment was used. Figure 5 shows the quotient of two simultaneously received spectra (warm/cold).

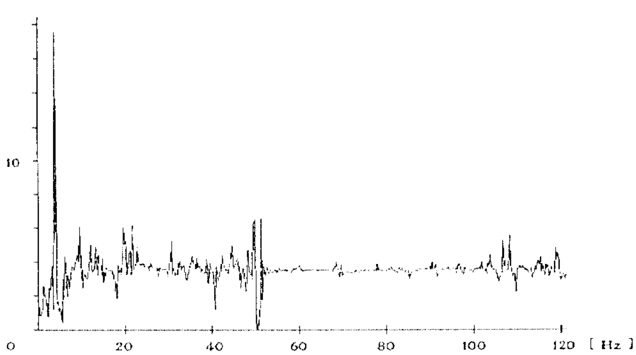

Fig. 5: Quotient spectrum: warm accelerometer/cold accelerometer

The line at 50 Hz is due to electrical noise. Especially at low frequencies the quotient spectrum shows a behaviour varying from measurement to measurement, due to the poor signal-to-noise ratio in this range. For different accelerometers the same calibration constant of 3.4 was found.

4 Results

Most of the measurements were made at the string-test set-up consisting of 5 magnets. Two accelerometers, one for the horizontal and one for the vertical direction, were mounted on the end plate of a helium vessel of a quadrupole. An analytic model of the suspension structure describes the magnet as a mass hanging at two springs. With Lagrange formalism the equations of motion were derived. With an estimation of the quadrupole mass and inertia momentum and after determining the stiffness of the springs, two resonance frequencies at 20 Hz and 71 Hz could be determined [2].

Experimentally resonance frequencies at 24 Hz and 74 Hz were found but the higher one is probably of minor importance because it corresponds to a mode with axis of rotation close to the center of the quadrupole (Fig 6). For the lower frequency, the resonant amplification was determined. The inner part of the quadrupole oscillates at 24 Hz with amplitudes 5 - 7 times higher than the vacuum pipe of the cryostat above the suspension point. It is now possible to estimate the vibration amplitude of the inner part of the quadrupole from a measurement made on the outside of the cryostat.

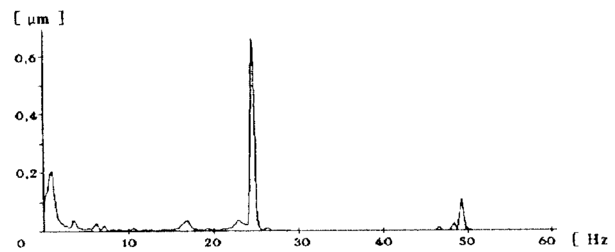

Fig. 6: Spectrum of vertical quadrupole motion at the string-test

By varying the helium flux from 30 g/s up to 45 g/s (design value for the HERA proton ring: 70 - 100 g/s) no dependence of vibration amplitudes on the helium flux could be observed. Vacuum pumps, which are necessary for the isolating vacuum have turned out to be an essential vibration source. These pumps vibrate at frequencies near the resonance frequency of the quadrupole.

Average vibration amplitudes of the proton quadrupole are 0.8 μm vertically and 0.6 μm horizontally. First measurements at a quadrupole in the tunnel show higher amplitudes, possibly due to higher helium flux, but this needs further investigations. Quadrupoles of the HERA electron ring vibrate with mean amplitudes of 0.6 μm horizontally. Analytical and numerical calculations show that the induced horizontal and vertical beam separation for uncorrelated magnet motion is not much more than a tenth of the respective beam sizes [2]. The effect on the luminosity is negligible but nevertheless the beam separation might limit the performance of HERA, namely because of diffuse emittance growth caused by the beam-beam interaction [3]. The effect of correlated magnet movement on the beam, due to ground motion is described in a separate paper [4].

5 Acknowledgement

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