Measurement of Proton Beam Oscillations at Low Frequencies

K. H. Mess, M. Seidel
DESY, D22603 Hamburg, Germany

Abstract

Ground motion and imperfect filtering of the power supplies result in micrometer level transverse oscillations of the proton beam in HERA at low frequencies and at multiples of 50 Hz. These oscillations have been measured by observing the modulation of the beam loss rate at a collimator. The signal level depends on the beam diffusion rate and may be calibrated during luminosity operation at HERA using a corrector coil driven by a sinusoidal current source.

1. INTRODUCTION

The measurement of transverse particle beam oscillations at low frequencies usually requires a sensitive pick up, observing the beam centroid, and associated detection electronics[1]. Such systems are susceptible to pickup noise at the line frequency of 50 (or 60) Hz and its harmonics, which makes the observation of small amplitude beam motion at these frequencies very difficult. The method presented here uses the frequency spectrum of the count rate from a coincidence detector observing beam loss; the coincidence rate and the subsequent signal processing are extremely resistant to pickup noise, so that low level beam oscillations are easily observed.

The observed rate depends on both the amplitude of oscillation of the beam and the transverse diffusion rate of the protons[2,3]. As the beam moves towards a fixed collimator the flux of intercepted halo particles increases. At the oscillation maximum the rate decreases rapidly to the diffusion rate, and as the beam moves away from the collimator, the rate will become smaller or even zero, depending on the diffusion rate and the frequency of the transverse motion. For very small amplitudes and low frequencies (compared with the refilling of the halo due to diffusion) the flux at the collimator can be calculated approximately to be in first order proportional to the amplitude. In general the beam will oscillate at more than one frequency, which introduces all possible cross modulation terms.

2. EXPERIMENTAL SETUP

The experimental setup is depicted in figure 1. The detector, one of the standard proton beam loss monitors in HERA [4,5], requires a coincidence between the output pulses from two overlapping PIN diodes. The discriminated pulse train goes to the equipment room in the HERA West hall, where the pulses are reshaped and sent through a low pass filter. The resulting signal is processed with a Fast Fourier Transform spectrum analyser. Typical count rates during the measurements were 100 - 1000 Hz.

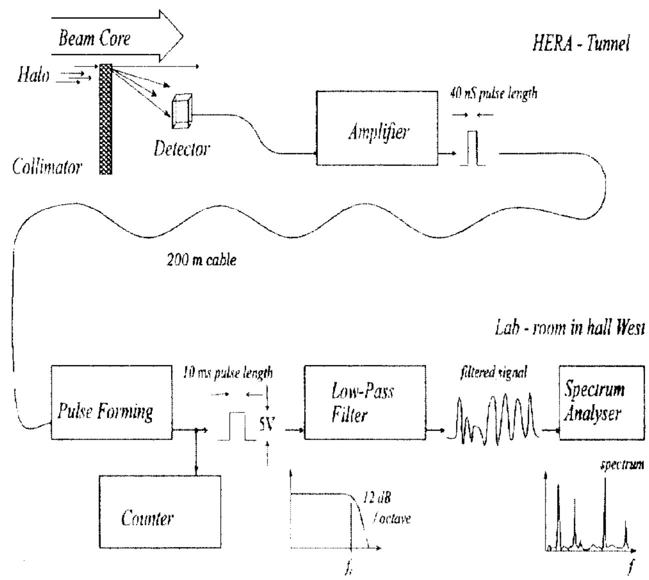

Figure 1. Experimental set up

The setup was tested for the presence of pickup noise by placing at the detector a radioactive source giving a count rate of about 500 Hz. Figure 2 shows the observed spectrum, which is flat except for a small decrease above 600 Hz due the mean count rate. No signal is visible at 50 Hz or harmonics thereof.

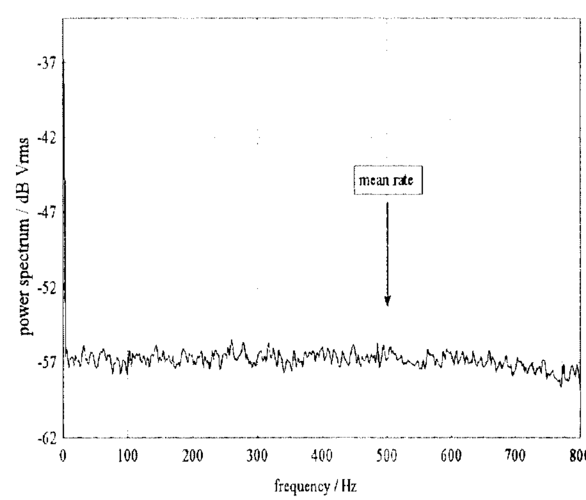

Figure 2. Spectrum of a radioactive source.

3. Experimental Results

As was pointed out, the observed rate depends on the diffusion rate in the proton beam. This is normally very small for 820 GeV proton bunches in HERA, unless they are colliding with electrons. Hence all measurements of the beam loss modulation were taken under luminosity conditions. Figure 3 shows a measured loss rate spectrum. The frequency spectrum of the mechanical motion of superconducting HERA proton ring quadrupoles has previously been measured [6] and is shown in figure 4 for comparision; many of the lines in the two spectra coincide. The quadrupole suspension in the cryostat shows resonances at 6 and 9 Hz. The lines at 24.4 and 48.8 Hz are due to some vacuum roughing pumps.

Above 50 Hz the spectra are populated with lines at multiples of the mains frequency. These modulations are obviously caused by magnet power supplies. Figure 5 and figure 6 show measurements made during two different luminosity runs, with similar but not identical conditions for the accelerators. In figure 5, there are strong lines at 300 and 600 Hz, while in figure 6, strong lines at 350 Hz and 700 Hz are present. In our opinion this indicates, that only a small number of power supplies contribute at a given time to the beam shaking, because a large number of sources would result in a stable average spectrum. One of the likely candidates is the main power supply for the bending magnets.

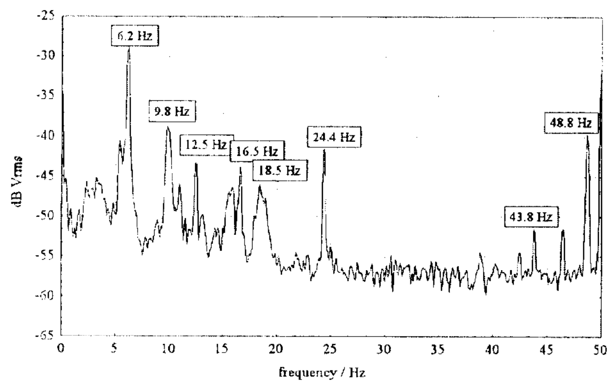

Figure 3. Frequency spectrum of the lost protons

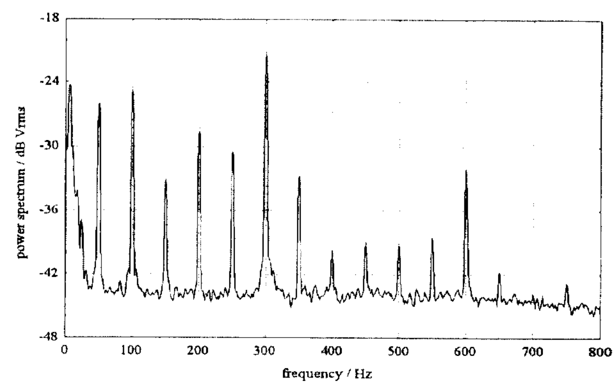

Figure 5. Frequency spectrum with a 300 Hz line

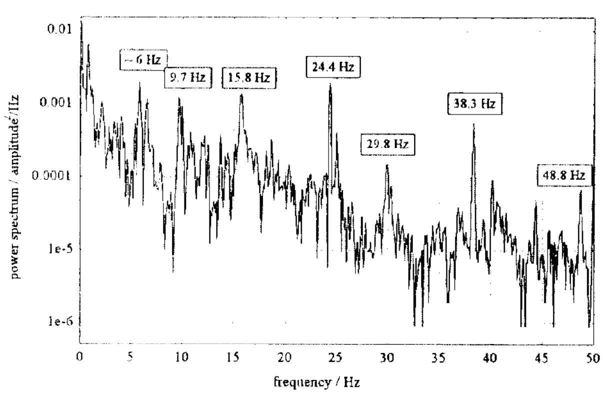

Figure 4. Spectrum of the ground or magnet motion

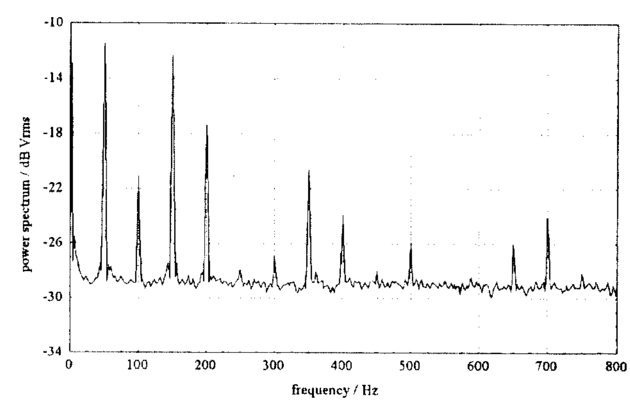

Figure 6. Frequency spectrum with a 350 Hz line

The electron synchrotron DESY II presents a load to the mains that varies at 12.5 Hz. The mains variations penetrate through power supplies to the magnetic field in some magnets of HERA. The line around 16.5 Hz may have something to do with the frequency used by the German railway. These two lines are absent in the ground/magnet motion spectrum.

It should be noted that tune modulation can also cause loss rate modulations due to the "breathing" of the beam [7], so that the observed loss rate includes contributions from ripple in the quadrupole currents.

For HERA, the main quadrupoles are connected electrically in series with the bending magnets, so that ripple on the main power supply affects both the bending and focussing fields.

As mentioned, an absolute calibration of the beam oscillation amplitude in terms of power in spectral line is not possible because of the changing accelerator conditions. On the other hand, during a luminosity run, the beam parameters change very little [3] and a relative calibration for a given diffusion constant and a selected frequency is possible. The proton beam orbit was corrected such that a particular superconducting corrector coil was not needed. This coil was then excited with a sinusoidal current from a power amplifier bypassing the DC power supply. The amplitude of the closed orbit modulation at the collimator location was calculated from the measured current using the known kick strength, β functions, phase advance between corrector and collimator, and accelerator tune.

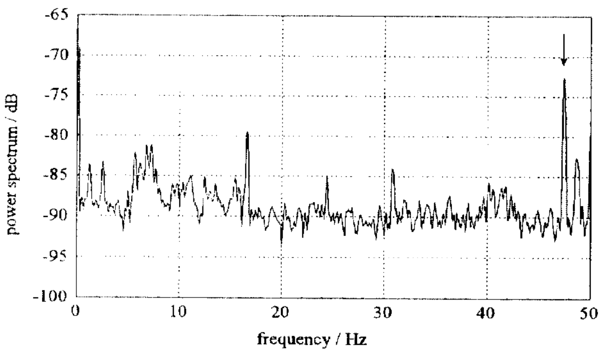

Figure 7. The beam loss spectrum during an artifical excitation of 8.6 μm amplitude at 47.5 Hz.

The proton beam was excited at several frequencies for which no lines were otherwise present. During these measurements no effect on the proton lifetime was observed. Figure 7 shows the measured loss rate modulation spectrum for an artificial excitation of 8.6 μm at 47.5 Hz.

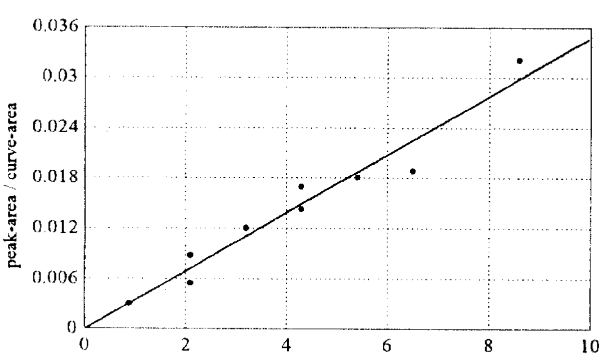

Figure 8. The relative beam loss depends linearly on the orbit kick amplitude (measured here at 47.4 Hz)

The corresponding enhancement in the spectrum is indicated by the arrow. Measurements at different excitation amplitudes but similar accelerator conditions share the same scale and hence can be combined. Figure 8 combines all measurements at 47.5 Hz as ratios of signal height over the total count rate and demonstrates that the signal is proportional to the kick amplitude over the range 0.5 - 8 μm. Using the information of figure 8 and of similar measurements at other frequencies, the orbit modulation amplitudes due to other sources can be evaluated; for example the roughing pumps cause modulation amplitudes at 24.4 and 48.8 Hz of ~3μm.

4. Planned Improvements

During the recent winter shutdown a larger set of detectors has been installed. The signal treatment has been simplified by using a multiscaler with a constant dwell time. The resulting counting rate distribution can than be Fourier analysed without any analog signal treatment. The larger size of the detector will extend the useable frequency range for the measurement to at least several kiloherz, and we hope that this will help in identifying the causes for the beam motion.

5. Acknowledgements

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6. References

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