Flywheel oscillation frequencies vertical and radial oscillations

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Description:

Measurements of the oscillation of the low-speed flywheel when supported by the superconductor-magnet thrust bearing were performed on March 15, 2016 in order to determine the natural frequency of oscillation and damping times for vertical and lateral (radial) oscillations.

The acceleration as a function of time was measured using a Gulf Coast Data Concepts X250-2 3-axis accelerometer/data-logger. The data sampling frequency was performed primarily at 512 Hz with 2 or 3 data sets performed at a frequency of 256 Hz. The resolution of the accelerometer was approximately 0.374 m/s^2, or about g/26.2.

Tests were performed by applying an impulse (using a rubber mallet) with duration shorter than the expected period of the natural frequency of the oscillations. For the vertical oscillation tests, the impulses were applied vertically (downward) at the center of sheet-metal plate attached to the top of the flywheel. For the lateral oscillation tests, the impulses were applied in a radial direction (inward) at approximately the height of the center of mass to within about +/-3 cm of the actual position of the center of mass.

The mass of the low-speed flywheel at the time of the experiment, not including the mass of the accelerometer or the metal plate, was 16.40 kg. Since these experiments were performed, the top cap ring of stainless steel was machined to receive a rotational encoder ring.

For the vertical impulse tests, the accelerometer/data-logger was secured to the top sheet-metal plate so that the accelerometers were located above the inner edge of the flywheel with the z-axis accelerometer orientated vertically. Placing the z-axis accelerometer at this location required the x and y axes of the accelerometers to be at an angle of about 30 to 45 degrees to the radial direction. Since it was the vertical motion that was desired, the requirement to specify the orientation of the x and y axes was relaxed.

For the lateral impulse tests, the accelerometer/data logger was secured to the top sheet-metal plate on the flywheel so that the accelerometers were located over the center of mass of the flywheel with the x-axis of the accelerometer in line with the direction of the applied impulse and the z-axis oriented vertically.

Several experiments were performed consisting of 4 or 5 impulses of various magnitudes applied per data set with 3 or 4 separate runs recorded for each the vertical and lateral oscillation experiments.

Summary:

All experiments to measure the vertical and lateral oscillations appear to be very consistent from run to run in their oscillatory behavior (frequency and decay time).

The acceleration as a function of time, the frequency spectra, and filtered acceleration as a function of time were plotted for one case each of a vertically and laterally applied impulse.

Vertical: The natural frequency of the vertical oscillations was approximately 11 Hz with a decay time of about $5/f_0$ or about 0.45 sec. (Figures 1-3) The effective dynamic spring rate,

$$k = 4\pi^2 m f^2 = 4\pi^2 (16.4\ \mathrm{kg})(11\ \mathrm{Hz})^2 = 78\ \mathrm{kN/m} = 78\ \mathrm{N/mm}$$

Lateral: The natural frequency of the vertical oscillations was 3.9 Hz. The decay time is extremely hard to determine but it appears to be about $3/f_0$ or about 0.75 sec. (Figures 4-6) Because the restoring force for lateral displacements is due to interactions between the permanent magnets and the high-temperature superconductors which are offset (i.e. below) the center of mass of the flywheel, the effect of a lateral impulse cannot be assumed to result in purely lateral motion. However, for purposes of estimation, assuming the subsequent motion as purely lateral, the system would have an effective dynamic lateral spring rate of 9.8 kN/m or 9.8 N/mm.

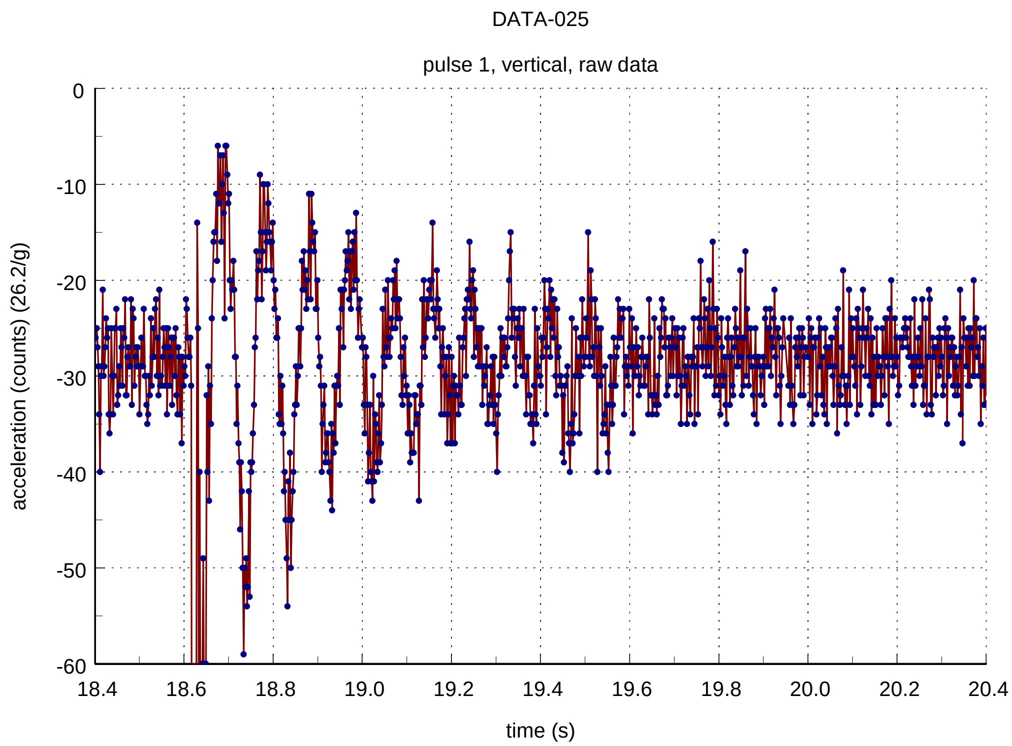

Fig. 1: Raw acceleration data for vertical oscillations. Data file DATA-025.

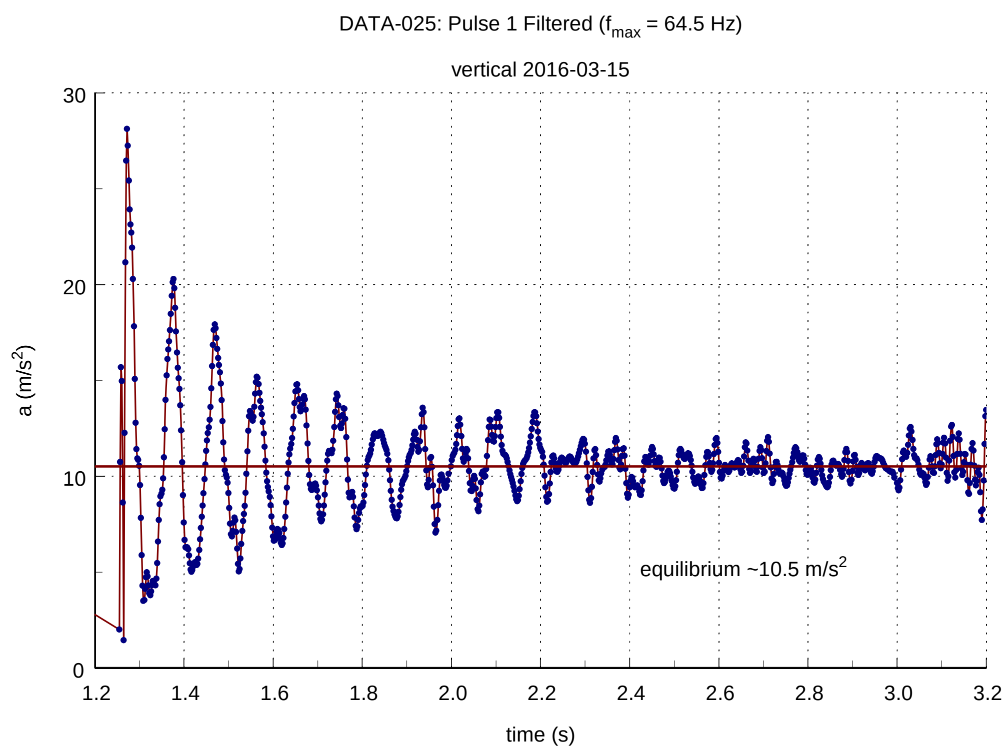

Fig. 2: Filtered acceleration data for vertical oscillations. Data file DATA-025.

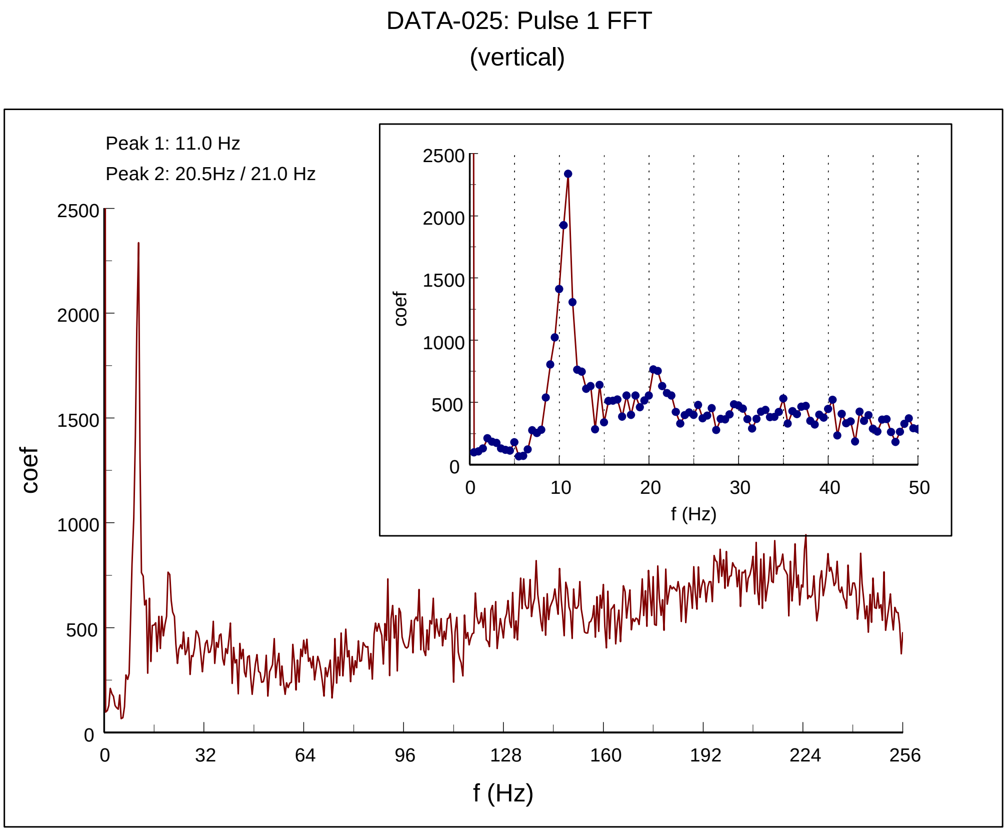

Fig. 3: Oscillation spectra data for vertical oscillations. Data file DATA-025.

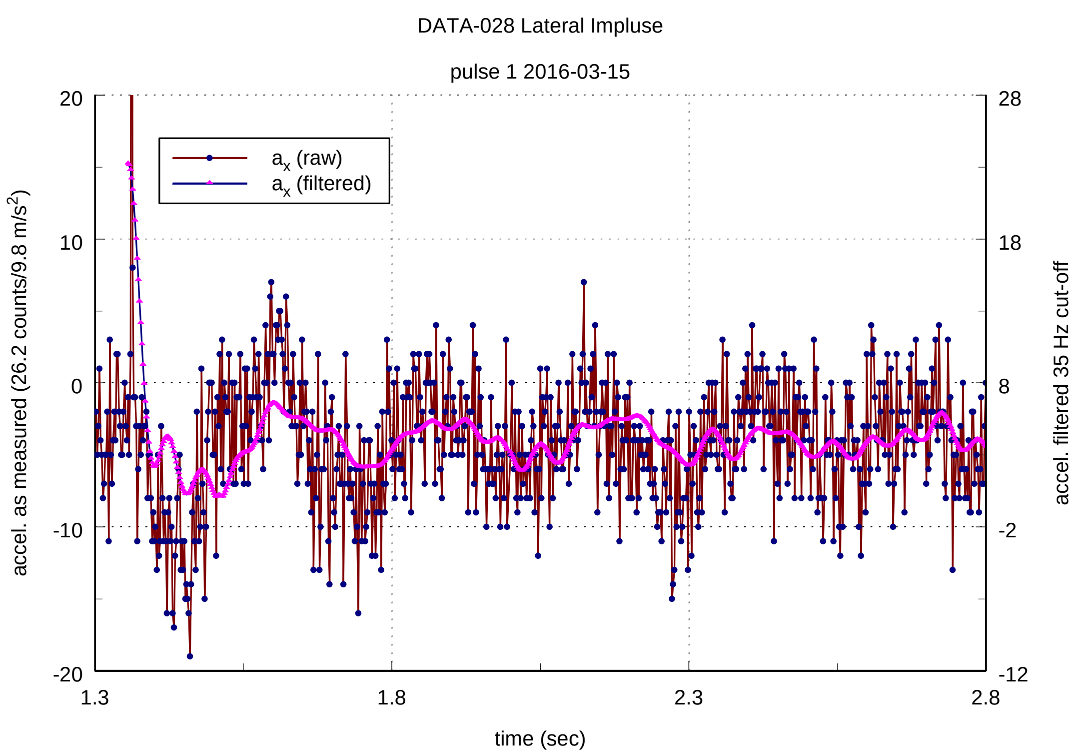

Fig. 4: Raw and filtered (f_{max} = 35 Hz) data for lateral oscillations. Data file DATA-028.

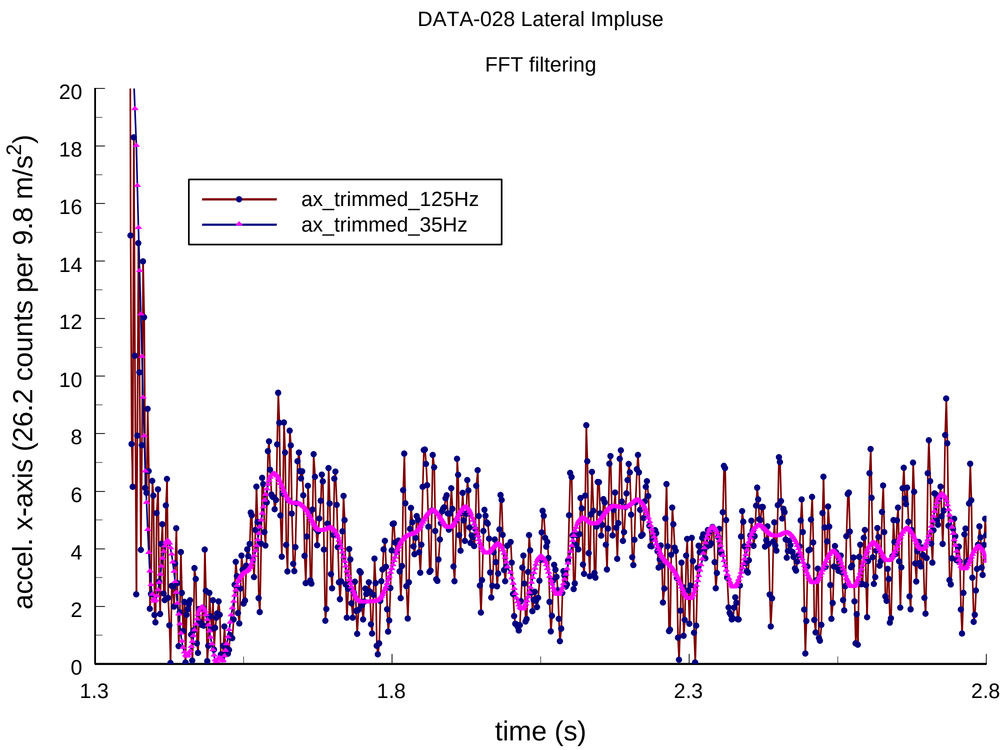

Fig. 5: Filtered (f_{max} = 35 Hz and 125 Hz) data for lateral oscillations. Data file DATA-028.

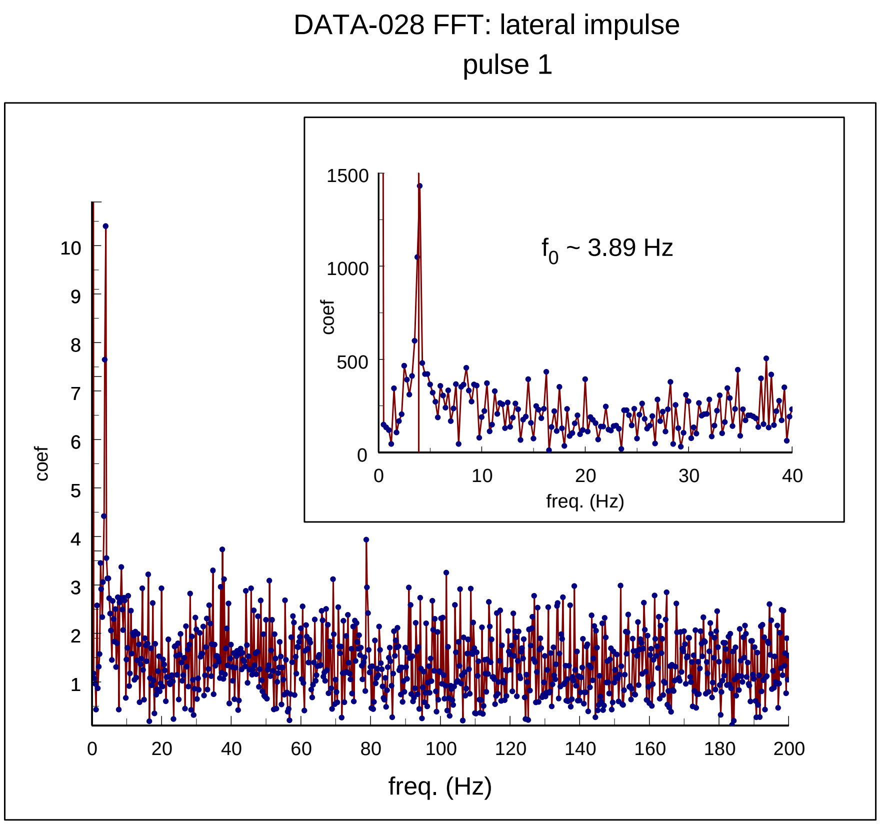

Fig. 6: Frequency spectra data for lateral oscillations. Data file DATA-028.