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SUPERCONDUCTING GRAVITY GRADIOMETER  
AND A TEST OF INVERSE SQUARE LAW

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The equivalence principle prohibits the distinction of gravity from acceleration by a local measurement. However, by making a differential measurement of acceleration over a baseline, platform accelerations can be cancelled and gravity gradients detected. In an in-line superconducting gravity gradiometer, this differencing is accomplished with two spring-mass accelerometers in which the proof masses are confined to motion in a single degree of freedom and are coupled together by superconducting circuits. Platform motions appear as common mode accelerations and are cancelled by adjusting the ratio of two persistent currents in the sensing circuit. The sensing circuit is connected to a commercial SQUID amplifier to sense changes in the persistent currents generated by differential accelerations, *i.e.*, gravity gradients. A three-axis gravity gradiometer is formed by mounting six accelerometers on the faces of a precision cube, with the accelerometers on opposite faces of the cube forming one of three in-line gradiometers.

Such an instrument is being developed at the University of Maryland under support from NASA with the primary geophysical goal being a dedicated satellite mission for mapping the earth's gravity field. The goal for the sensitivity of this instrument was set by a 1983 workshop at  $3 \times 10^{-4} \text{ E Hz}^{-1/2}$ . Additional scientific goals are a test of the inverse square law to a part in  $10^{10}$  at 100 km, and a test of the Lense-Thirring effect by detecting the relativistic gravity magnetic terms in the gravity gradient tensor for the earth.

The expression representing the intrinsic spectral noise of the gradiometer consists of two terms: a Brownian motion noise term and an amplifier noise term. In addition to the scaling of the intrinsic spectral noise with one over the baseline squared, the determining parameters for the Brownian motion noise level are the mass, the temperature, and the quality factor; whereas, the determining parameters for the amplifier noise level are the resonance frequency and the energy resolution of the amplifier.

The intrinsic noise level for the three-axis gradiometer currently being tested is  $2 \times 10^{-3} \text{ E Hz}^{-1/2}$  and is limited by the amplifier noise term. In order to meet the 1983 workshop goal with a presently available commercial SQUID, the resonance frequency must be reduced. One way of accomplishing this reduction is by means of a superconducting negative spring. The negative spring consists of a superconducting disk with curved edges located in a short superconducting solenoid with a length less than the thickness of the disk. The negative spring has been demonstrated and is being incorporated into the latest model of the superconducting gravity gradiometer.

Though it appears that the goal for the intrinsic noise level can be met, the best sensitivity demonstrated in the laboratory to date is  $0.05 \text{ E Hz}^{-1/2}$  at 1 Hz, degrading at lower frequencies. The source of this noise appears to be modulation of the earth's gravity by residual tilt noise. This modulation occurs as a result of sensitive axis misalignment and scale factor variations. In order to remove this and

other angular motion errors, a six-axis superconducting accelerometer is being developed at the University of Maryland under support from the Air Force Geophysics Lab. This device consists of a superconducting proof mass in the shape of an inverted cube. The motion of this proof mass is sensed in all six degrees of freedom (three angular and three linear) with superconducting bridge circuits. These bridge networks are modulated at six different frequencies and the signals are sensed with a single SQUID amplifier. This accelerometer has been designed to occupy the center of the precision cube of the gradiometer.

The gravity gradiometer project at the University of Maryland has progressed to the point where a study team has been formed to examine details and make recommendations to NASA with regard to a super-conducting Gravity Gradiometer Mission. The study team has drafted a report which will soon be published.

As previously mentioned, one of the scientific goals of such a mission(s) would be an inverse square law test to an accuracy of 1 part in  $10^{10}$  at 100 km. This test would attempt to resolve a non-Newtonian potential by measuring the Laplacian of the earth's gravitational potential. In a circular polar orbit at 160 km altitude, which is preferred for the geophysical mission, the oblateness of the earth would be the source. With a mission duration of 180 days, the stated resolution could be achieved. However, this experiment is not a straightforward one. In order to minimize the effect of attitude rate variations, an inertial orientation must be chosen. One of the three sensitive axes could be oriented normal to the orbit plane to circumvent the limitation of 1 part in  $10^5$  that would be imposed by the axis misalignment. There still remains a challenge in matching the scale factors to 1 part in  $10^{10}$  in the measurement bandwidth. This would require some sort of continuous cross-calibration of the gravity gradiometers.

#### DISCUSSION

NIETO: A two part question; (1) You don't need a shuttle mission, do you? (2) If you got the go-ahead yesterday, how long would it take you to prepare your package?

MOODY: No and mid 90's.