LACOSTE & ROMBERG AIR-SEA GRAVITY METER VIBRATION TESTS

Introduction.

Our motivation is to compare the vibration sensitivity of our new AirSea II system to the ZLS D-003 (fluid damped) and S-32 (air damped) marine gravimeters presented in a recent article on the Grav-Mag server written by Austin Exploration. In this paper, the ZLS system was perturbed using an electric kitchen knife as a vibration source. The two resulting plots show that while D-003 is practically insensitive to the electric kitchen knife's vibration, S-32 meter appears to have a sensitivity of about 5-10 mGal (no scale given) to the kitchen knife's vibration. We do not think this is a normal problem with properly tuned L&R Air Sea meters.

Summary.

We present our vibration sensitivity results using a scientifically designed vibration test table and three L&R Air-Sea gravity meters. The test vibration was applied through the testing table to the base or mounting plate of the meter, thus letting the meter, gimbal, shock cords, and air dampers work as a system. Our testing shows that when vibration is applied to the meter with an amplitude larger than found in aircraft or ships the resulting change in the gravity reading is insignificant.

An advantage of our tests is that we utilized a standard vibration source that provides calibrated and reproducible accelerations. Our vibration table is also capable of precisely measuring the response of the gravity meters to accelerations in different directions. Our vibration table avoids the major weakness of the Austin Exploration tests in that the vibration source (electric kitchen knife) used in their tests did not provide a uniform and calibrated vibration characteristic. Thus it is impossible to know the amplitude and frequency or even the precise direction of the acceleration that was given to the ZLS meters. It is also impossible to verify that the kitchen knife provided exactly the same vibrations to different gravimeters due to difficulties in coupling the vibration and the limited force available by the device. Moreover, the source used in the Austin Exploration tests are not calibrated which means that their results are not reproducible by other groups.

We also modeled the theoretical transfer function of the system formed by the meter, gimbal, gimbal suspension, and shock absorbers. The output of these models confirm our testing results that noise is highly attenuated by the meter suspension.

Our vibration testing tools.

Every meter is tested using our vibration equipment to determine its vibration sensitivity. Then shock absorbers' optimum pressure is set individually for each meter and the results are recorded in the meter book for that meter. The set of tools comprising our vibration test lab include:

VIBCO Adjustable Vibration Table.
2x ICS 3022-002 accelerometer.
Tektronix TDS 460 Oscilloscope.
National instruments DAQCard-AI-16E50.
Labview data analysis package.

Figure 1 Typical vibration testing setup.

L&R Sensor Vibration Sensitivity Test.

The purpose is to find and correct any meter with an abnormal sensitivity to vibration in any direction. We are interested in finding at which frequencies the sensor has resonances. The test procedure to perform this test is as follows:

The meter is mounted on the vibration table with the air shocks removed. An accelerometer is located on the base plate. The amplitude of the excitation vibration is recorded. For this test a very large RMS value of excitation is used because we want the vibration transmitted through the low pass system formed by the gimbal and shock cords to be large enough to excite any possible resonances in the sensor itself. A range of frequencies are swept through and the results recorded.

The results are:

10 to 20 Hz. No significant errors in gravity were found in this range of frequencies for any of the three meters. The applied vibration amplitude was 100 mg (milli-g) RMS.

20 to 60 Hz. We found errors as large as 20mGal at approximately 40 Hz for the worse case and the average error was 17 mGal. The applied vibration amplitude was 200 mg RMS. In this range the meters show their maximum sensitivity to vibrations.

We suspect the meter spring has its main resonance in this range. Other possible sources of resonances in this range would be in the screw lever system arms.

60Hz to 100 Hz. In this range smaller errors were found; 5 mGal in the worse case and 0.5 mGal for most of the meters tested. The applied vibration amplitude was 500 mg RMS.

The next figure shows the results for three different meters with the air shock absorbers removed and when vibration larger than is found on planes or boats is applied to the base plate.

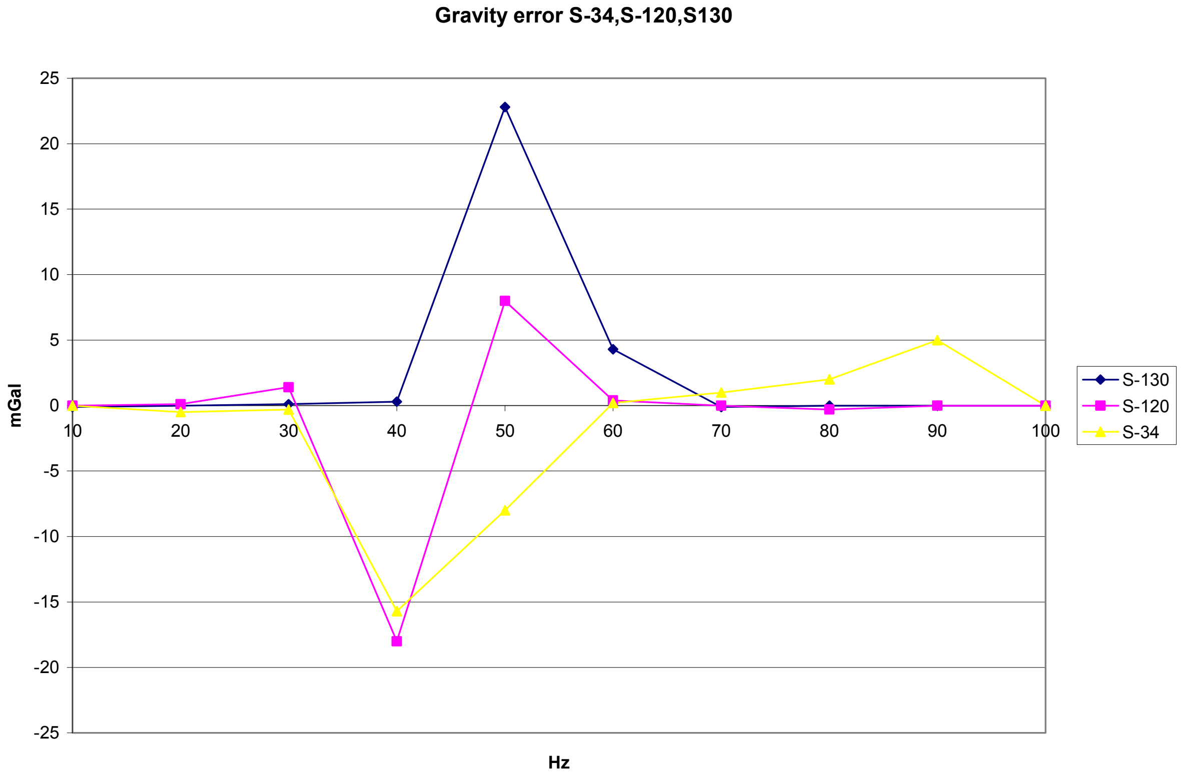

Figure 2 Error of gravity reading vs. frequency when applying large vibrations with no air shocks.

Air Shock Mount Optimum Pressure Test.

The shock mounts used below the L&R meter frame are air filled. The shocks can be pressurized in the range of 0 to 60 psi. Our testing shows there is a correlation between the pressure in these shocks and how well the shock absorber performs in absorbing vibration. The purpose of this test is to find the optimum air pressure for the shock absorbers. The procedure to perform this test is as follows:

The meter is mounted on the vibration table with the air shocks installed. An accelerometer is located on the base plate. Three shock absorber pressures are tested with a range of frequencies and the results recorded.

0 psi. The system behaves as if no air shocks were used. (too stiff)

25 to 35 psi. The performance of the air shocks is optimum and negligible errors are obtained.

50 psi. The performance of the air shocks degrades and an error of up to 5mGal may appear. (too stiff again)
The next figure shows the error in gravity at different frequencies for three different pressures on the shocks for meter S-130. Results are similar for other meters.

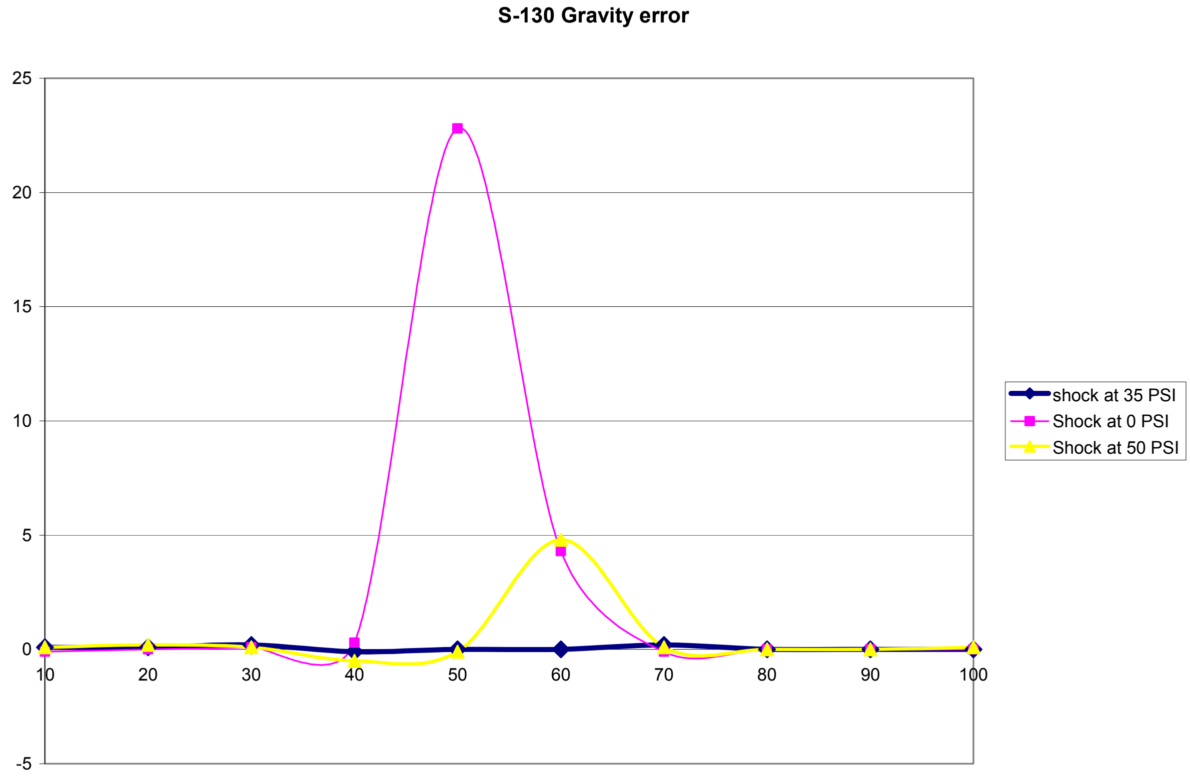

Figure 3 Gravity errors at different pressures and frequencies.

Every new meter or serviced meter is tested and a optimum shock pressure found. Once the optimum pressure is known a label is applied to the meter frame with the optimum range of pressures. Note that the vibrations applied during the test have amplitudes larger than would normally be found in real surveys.

Results with optimized sir shock absorbers.

The meter is tested again on the vibration table with the same level of vibration as before but with the shock absorbers installed. The next figure shows a plot of the error obtained at different frequencies:

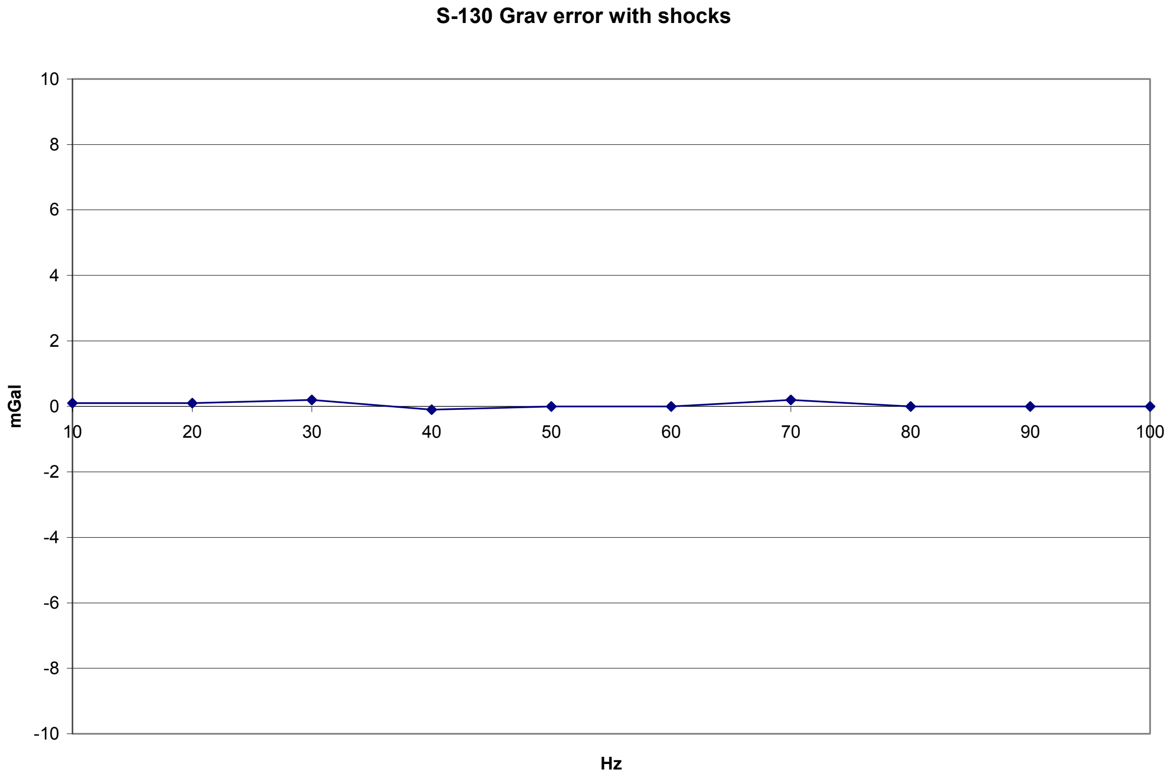

Figure 4 Gravity error when optimized air shocks are used .

L & R Air – Sea meter suspension model:

The inner suspension model.

The L&R meter gimbal to frame suspension can be modeled as a single degree of freedom spring, mass, and damper system.

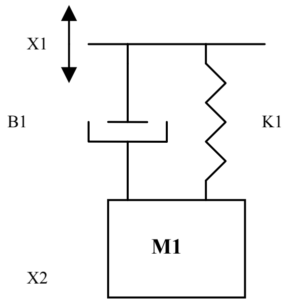

Fig1 Single degree of freedom gimbal suspension equivalent model

Approximate measured values for the L& R meter :

M1=57.6 Kg (mass of gimbal plus sensor)
K1=4826.4 N/m
B1=206 N Sec/m

The model of figure 1 has can be represented by the next transference function:

$$\frac{X_2(s)}{X_1(s)} = \frac{\frac{B}{M1}\cdot S + \frac{K1}{M1}}{S^2 + \frac{B1}{M1}S + \frac{K1}{M1}} = \frac{3.576\cdot S + 83.79}{S^2 + 3.576\cdot S + 83.79}$$

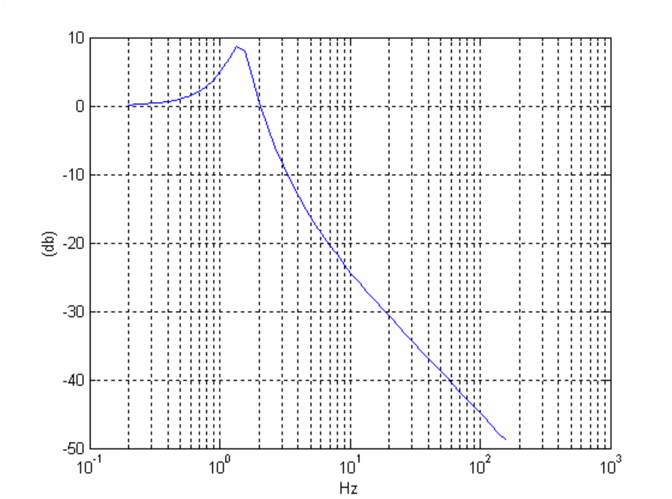

Figure 2 Transfer function of the L&R suspension

The air shock absorbers (outer suspension model)

The current air shock absorbers present a transmissibility response shown in the next figure

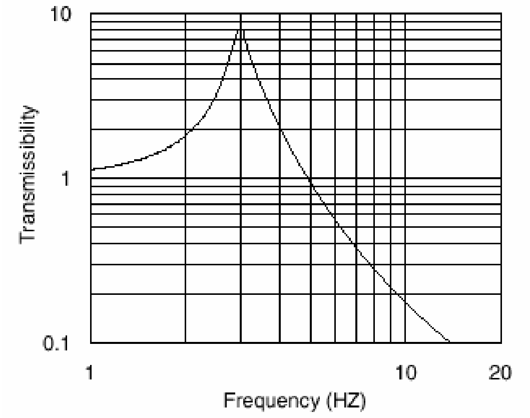

Figure 3 Transmissibility of the shock absorber at is nominal load

The Transmissibility function of the system of the frame and shock absorber can be modeled as

$$\frac{X_3}{X_2} = \frac{5.345\cdot S + 355.3}{S^2 + 5.345\cdot S + 355.3}$$

Transfer function of full sytem.

The total transfer function from base plate to sensor can be modeled as

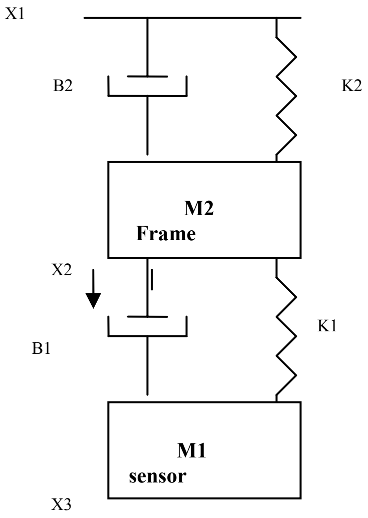

Fig 4. Block diagram of the gimbal plus shocks

For the outer (second)stage:

K2=26500 N/m (air shocks)
B2= 1000 N-sec/m
M2=17.23 Kg (mass of frame)

The total transmissibility from base plate to the to the sensor for vibration applied in the vertical axis of the gravity meter is given by the next transfer function:

$$\frac{X_3}{X_1} = \frac{210.4 \cdot S^2 + 10518.8 \cdot S + 131025}{S^4 + 74.5 \cdot S^3 + 2141.5 \cdot S^2 + 10518.8 \cdot S + 131025.3}$$

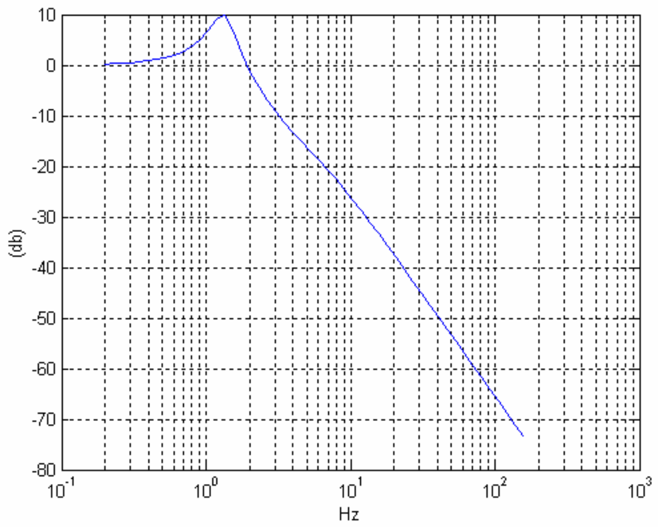

Figure 4. Transmissibility of the signal from base plate to sensor

As we can see, the suspended gimbal plus the shock absorbers form a 4th order low pass filter. This system attenuates vibration in a range from 30dB to 80 dB at all the frequencies that can affect the meter.

Conclusion.

With proper pressure in the air shocks, Lacoste and Romberg Air-Sea gravity meters (air damped) show negligible errors in gravity due to vibration in the 0-100 Hz range at any amplitude reasonably expected in the field. The meter must be treated and used as a system and must be properly set-up in order to obtain the best results. It is possible that a poorly tuned gravimeter can respond with inferior results but this is not a problem if the system is set up correctly.

Finally, it is impossible to compare our results with the results of the Austin Exploration tests of the ZLS meters because it is not clear what vibrations were provided by their vibration source (kitchen knife) and if they were identical in all of their experiments. It is also not clear if all the meters have been optimally tuned to provide maximum vibration isolation. It would be a very good idea to put all of these instruments through the same level of testing to find out the relative advantages of the different systems. However, our tests make it clear that the LaCoste & Romberg gravity meter systems are an excellent gravity meter for dynamic applications.

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