13 Myths About Vertical Feedback Seismometers:

including some things I believed before
helping design a real feedback instrument

Brett Nordgren

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1. The longer the natural period of the spring-mass assembly, the better.

2. The spring is a significant element in seismometer dynamic performance.

3. The pivot flexures must be designed for extreme 'softness'.

4. Larger mass is better.

5. Forcing coils should have the highest Newtons/Amp possible.

6. The position sensor must be very linear.

7. The position sensor must allow for substantial boom motion.

8. Mechanical clearance in the forcing coil assembly is a problem as the boom rotates

9. Capacitor sensor plates must never touch.

10. A leaf spring needs to be made of Ni-Span-C or some other exotic material to avoid temperature drift.

11. Variations in the magnet and forcing coil (with temperature) are of little importance.

12. Component noise originating at the input of the feedback path is more important than noise originating near its output.

13. Measurement of a feedback loop is best done with the feedback disconnected.

1. ***The longer the natural period of the spring-mass assembly, the better.***
   Perhaps slightly, but the resonant frequency of the spring-mass is not directly related to performance and a free period of a few seconds will work fine. However, it is good for the support spring to have high compliance, i.e. a low spring constant in order for the loop gain to be high at the lower frequencies, and high compliance generally implies a low resonant frequency. It is probably OK to adjust an astatic spring for infinite period, with the understanding that after a small temperature change it will either become unstable or settle at some higher, non-zero, frequency. The instrument performance with feedback active will not be significantly different in either case.

2. ***The spring is a key element in instrument dynamic performance.***
   No. The main purpose of the spring is simply to support the mass near the center of the position sensor range, so that the forcing coil does not need to 'work' so hard against gravity to keep the boom centered. Additionally, the spring should be designed to have minimal force change as the mass moves, so that the feedback loop can be fully in control, i.e. have high loop gain. The spring exists to relieve the burden of supporting the mass from the electronics. In fact, a feedback vertical can be made which has no spring at all. However the dynamic range of the feedback integrator would have to be made large, and as a result its long-period noise would likely be excessive. So having a spring will definitely help performance, it's just not a key element.

3. ***The pivot flexures must be designed for extreme 'softness'.***
   Maybe. Some excellent feedback designs have used surprisingly stiff flexures. The effect of a stiff flexure is to raise the spring-mass natural frequency, an effect which can be compensated for by shortening the leaf spring. In some designs we have found that the spring had to be shortened to a degree that its stress level became too high so softer flexures became necessary. It is probably good to try to use the thinnest and most flexible pivot flexures which will be strong enough.

4. ***A larger mass is better.***
   In general, no, unlike in non-feedback instruments. Since the forcing coil must be able to generate sufficient force to balance the maximum ground acceleration forces at all operating frequencies, the current and voltage available from the electronics to drive the coil must be large enough. A large mass makes that more difficult, and ordinary low-noise IC's may not be up to the task. Modern feedback seismometers generally use a mass value of the order of a few hundred grams--often significantly less. The smaller the mass, the easier it is for the feedback loop to control it.

5. ***Forcing coils should have the highest Newtons/Amp possible.***
   Usually making a coil with a high Newtons/Amp value implies winding with many turns of fine wire, which results in a high coil resistance. But since the op amp outputs in the feedback circuit are usually limited to 10-20 Volts maximum, a high coil resistance, implies a relatively low maximum coil current. It is usually better to try for an appropriate Newtons/Volt figure, which requires using somewhat larger wire. The ideal coil resistance value would match both the maximum voltage and maximum current available through the feedback branches. Additionally, the Newtons per Amp value should be appropriate to the value of the seismic mass.

6. ***The displacement sensor must be very linear.***
   For non-feedback systems, sensor linearity is very important. However, in a good feedback design, the sensor will move very little. Therefore what is most important is its sensitivity around the one operating point and its position stability, not its linearity.

7. ***The position sensor must allow for substantial boom motion.***
   Since the boom does not move significantly in a good feedback design, the plate gap in a capacitance position sensor may be quite small, 0.5-1mm or even less, which can allow it to be quite sensitive. The main challenge in constructing such a narrow-gap sensor is maintaining the sensor plates sufficiently parallel.

8. ***Mechanical clearance in the forcing coil assembly is a problem as the boom rotates***
   See 7. Since in a good feedback design the boom does not move, clearances may be quite small.

9. ***Capacitor sensor plates must never touch.***
   It all depends on the sensor electronics. Some attractive designs continue to generate voltage of the proper polarity even when plates are shorted. Other designs can have the voltage going to zero or even reversing polarity when one sensor capacitor is shorted, neither of which is good, and with such designs the plates must be kept from touching.

10. ***A leaf spring must be made from Elgilloy or some other exotic alloy to avoid temperature drift.***
    In very high-performance instruments, the dynamic range of the integral feedback is made small in order to limit the amount of long period noise it can inject. It therefore can handle only relatively small changes in the spring force before the instrument must be mechanically rebalanced. In order to reduce the amount of adjustment needed, the spring can be made of some exotic low TC of Elasticity alloy, which permits the integrator to maintain centering over a wider temperature range. It is quite easy to increase the dynamic range of the integrator sufficiently to allow it to handle the variation from temperature change seen with an ordinary steel spring. The price to be paid is about an order of magnitude increase in one contribution to long-period noise. In addition, with a steel spring the instrument response to temperature-change rates will be about 10x higher. However in all but the most demanding professional applications that does not seem to be a major problem.

11. ***Variations in the magnet and forcing coil (with temperature) are of little importance.***
    Both the coil resistance and the magnet strength vary with temperature. Since these components are in the feedback path, the instrument sensitivity will track variations in the magnet and to some degree, of the coil. Variations in the derivative feedback capacitor value also affect the sensitivity.

12. ***Component noise originating at the input of the feedback path is more important than noise originating near its output.***
    Normally noise originating at the input of an amplifier string has a greater effect on the signal to noise ratio than noise inserted near the output of the string. As with most things relating to feedback networks, everything is upside down and backwards. Noise inserted at the output of the feedback network, such as at a coil driver has the greatest impact on instrument signal to noise performance, and noise introduced at the input to the feedback path has the least negative effect.

13. ***Measurements of a feedback loop can be made with the feedback disconnected.***
    As soon as the loop is broken it loses its ability to maintain its operating position. The boom goes to an extreme and all amplifiers are saturated in one direction or the other. The same thing occurs when a component fails, making inoperative feedback systems confusing to troubleshoot. For testing a working loop, there are special methods for breaking into the loop without disabling it, and when troubleshooting, one needs to use techniques appropriate to feedback circuits.