Calibrating the Inyo FBV Seismometer

Draft Copy - 23 July, 2010

Brett Nordgren

It is quite possible to build and operate the Inyo without knowing its exact calibration, so long as the mechanical and electrical specifications are followed reasonably closely. You could expect to have a velocity response which is likely to be within 20% or so of the values predicted by the Loop7 spreadsheet. High quality commercial instruments have a velocity response specified to within ±1%, although it is expected that they will need to have their calibrations checked occasionally.

It should be possible to measure the response of the Inyo to an accuracy of close to 1% and by properly selecting a number of its resistors, even to achieve a particular response by design. A number of factors act to vary its calibration during operation, in particular the temperature sensitivity of the forcing-coil magnet and the capacitance temperature coefficient of the derivative-branch capacitors. But, with relatively constant temperature, the Inyo should be able to maintain its calibration quite well over a considerable period of time.

It is customary for each seismic station to report the calibration factors for each of its instruments and to update that information whenever recalibration is done. Similarly for the Inyo data to be scientifically useful, it will be necessary to know and report its calibration results.

We will consider two types of calibration problems. The first, which is the more difficult, is to assemble a new instrument to accurately match a desired response curve. Easier, is measuring the V/m/s 'generator constant' of an operational instrument.

When initially assembling the seismometer a number of measuring instruments are useful or necessary:

First, a means of accurately measuring resistor values is required. Depending on the quality of the available ohmmeter or resistance bridge it may be necessary to correct its calibration by measuring a standard resistor whose resistance is in the general vicinity of the resistor being measured. A good resistance standard can be obtained by using 0.1% metal film resistors, generally available from parts distributors for a dollar or two each. In some cases it might be reasonable to simply use 0.1% resistors in the instrument in places where their values determine the calibration. That has the additional advantage that the 0.1% parts can be found with values which are closer to the required values and their temperature coefficients of resistance will usually be lower.

Capacitors also need to be measured, though that is harder, as most capacitance meters are not very accurate. When using one, check the manufacturer's specifications. I have seen 3 and 4-digit capacitance meters whose accuracy was only guaranteed to be 3 or 4%. One approach to getting more accuracy would be to have one of the 10uF capacitors measured with a good (=expensive) capacitance meter and then use that as a standard to correct the measurements from a less expensive meter.

A good-quality digital multimeter would be adequate for most measurements, particularly if its accuracy could be checked against some known standards.

Some sort of weighing scale will also be needed, one with a range of 0-200g and an accuracy of perhaps ±0.1g. And finally a micrometer or micrometer head will be useful when measuring the displacement sensor sensitivity.

Different elements will contribute different amounts to the calibration errors. Capacitors will probably introduce some of the larger errors as they are not commonly available with tolerances better than ±10%, while resistors may be easily obtained with tolerances of ±1% or better. Also significant is the forcing coil coefficient, Gn, which will depend on the coil winding characteristics, the magnet strength and the steel armature properties, all of which will be somewhat uncertain. The displacement sensor sensitivity may also be slightly uncertain, though its effect on the instrument performance will be less significant, so long as it is approximately correct. Finally, it will be important to know the boom mass and mass distribution, which will mostly depend on the coil weight and the boom construction details.

In general, a particular response curve may be obtained by selecting various resistor values in order to compensate for variations in the capacitors, the forcing coil Gn and the boom mass characteristics.

Referring to the schematic, particular resistors have different effects.

R9 determines the feedback loop's generator constant, its V/m/s in the mid-frequency region, compensating for variations of Cd, Gn and M_0, the boom mass.

R3 sets the inverse filter high-frequency zero, and compensates for the tolerance of C1.

R4 sets the span of the inverse filter, which affects the low-frequency loop gain--not a calibration issue, but one which is possibly related to reducing low frequency waveform distortion and drift.

R2 can adjust the overall sensor gain, r_t, to the desired value, adjusting for variations in the displacement sensor circuit sensitivity and the effects of the choices for R3 and R4.

Ri is not involved in calibration, but is instead related to the temperature range over which the instrument is intended to operate. Its value must be low enough to handle the maximum expected temperature variations, but high enough to not introduce excessive long-period noise from the integrator Op Amp.

R5 determines the low corner frequency of the instrument response, correcting for the tolerance of Ci and the choice of Ri.

Rp corrects any peaking at the instrument's low corner frequency and is a function of that frequency and the loop's generator constant.

The output amplifiers are assumed to be accurate within a percent or two, but may be checked and trimmed if desired. The gain of the low-gain output amplifier is given by R27/R23, which is nominally 2.004. The high gain-output is amplified by an additional factor, given by R12/R14, nominally 50, resulting in a nominal overall gain of 100.2. These gains multiply the loop generator-constant and determine the overall instrument generator-constants at the low and high-gain '+' output terminals. Note that the 'LOW - ' output terminal is only used to provide a differential signal for a 24-bit digitizer.

Measurements:

It will be helpful to first measure the capacitors making up Ci and Cd as well as C_1, as their values will be needed in the calibration process. Then the boom mass, M_0, the displacement sensor gain, R_{sensor}, and the forcing coil constant, G_N, will be measured.

First, the instrument should be assembled without the spring and the effective boom mass measured by a sensitive scale, supporting the beam at a point which is the same distance from the pivot as the center of the coil/magnet, so that it is level. That gives M0. When using particularly flexible (Kapton) flexures, watch to be sure that without the spring, they don't flex downward too much.

To measure the sensor gain, remove jumpers JP1 and JP2 and unplug the connection to the forcing coil. Arrange for the boom to seek its upper stop, either by installing and adjusting the spring or by means of an external spring such as a rubber band gently lifting the boom. Mount a micrometer or micrometer head to press down on the boom at the same distance from the pivot as the center of the coil. Mount the micrometer so that it can move the boom over its vertical range. Starting with the boom approximately centered, connect a meter to the 'POS ERR' output, pin 7 and turn on the electronics. After the voltage stabilizes, using the micrometer, move the boom in steps in both directions from center over about half its range, approximately ±0.4mm or ±0.015", while recording the micrometer readings and corresponding output voltages. The slope of the data curve at its zero-volt point (change in voltage/change in position in mm) should be approximately 12.5V/mm, which, multiplied by R6/R10 (nominally 1/10), will give the value of r_{sensor}.

G_N can be measured with the instrument assembled and operating normally. First record the coil resistance, Rc, and the measured value of Ri. Attach an accurate voltmeter to the "CENT FORCE" output, pin 6, and turn on the seismometer. After it stabilizes, record the voltage, V_{CF}, then place a 500mg weight on the top of the boom at the same distance from the pivot as the center of the coil. If necessary, any small non-magnetic object, whose weight is known, such as a #6 brass washer, may be used instead of a 500mg standard weight. After the output on pin 6 settles, record the new voltage. The coil constant Gn = W/ δV_{CF} * 0.00981* (Ri+Rc)   N/A, where W is the test weight value in grams.

For example, if adding a test weight of 0.5g results in an output voltage change of 3.86V and Ri = 12,000 Ohms then Gn = 0.5/3.86 *0.00981 x (12,000+50) = 15.31 N/A Or for greatest accuracy you could multiply that by R19/R21, as measured, instead of assuming the nominal ratio of 1.0.

For simple recalibration it is only necessary to have a Voltage source which can produce a sine wave having a frequency in the range of 1/10 to 1 Hz and having an accurately known voltage of several Volts, along with a means of accurately measuring the resulting seismometer output voltage. The voltage measurements can possibly be made with the same A/D setup planned for recording the outputs of the operational instrument.