

Note:

The trim-mass configuration has been somewhat flexible and has frequently changed as the various FBV prototypes have evolved.

One promising arrangement consists of a main trim weight mounted on a vertical screw so that its vertical position may be easily adjusted. This is combined with a secondary trim weight consisting of one or more thumb nuts riding on a horizontal screw, which is used to fine-tune the boom balance.

For the Inyo a good trim mass may be made from 3/4" round brass bar stock, having a length as determined to be appropriate for the particular instrument.

This trim mass design is assumed in the following discussion.

Mechanical Setup for the FBV Seismometers

Brett Nordgren

13 April, 2011

Goals: The mechanical adjustments to the FBV seismometers are intended to achieve four goals.

- 1) At rest the boom is nearly horizontal.
- 2) The free-oscillation period is reasonably long--3 seconds or so.
- 3) The instrument has minimal sensitivity to horizontal motion.
- 4) Free-oscillations are symmetrical about the boom rest position, with no tendency to stick at either extreme of motion.

Starting with the assumption that the boom mass distribution and geometry is close to the original design, four things must then be correctly adjusted to achieve these four goals.

- 1) the magnitude of the trim mass
- 2) the spring length
- 3) the horizontal location of the trim mass
- 4) the vertical location of the trim mass

Since these all interact to a considerable degree, it becomes necessary to home in on the right combination by systematically repeating the adjustments.

Note that the adjustment of the spring length between the clamps is extremely sensitive. A change in clamp position of a few thousandths of an inch, makes a significant change to the free period.

The horizontal location of the main trim weight is fixed by the location of its mounting screw. However, its effective location may be adjusted slightly by means of one to three thumb-nuts riding on a horizontal screw, acting as a secondary trim weight.

Procedure

With the electronics turned off and the sensor board removed:

(1) Set the thumb-screw(s) to the center of their adjustment range. Start with less trim mass than expected and with the base plate leveled, adjust the spring length for approximate balance.

(2) At this point the sensor board can be installed and the feedback loop tested. The feedback should position the boom nearly level and the Integrator (Centering Force) signal should not be too large and should respond (slowly) to any small adjustment of the thumb nuts. Shielding the instrument from drafts and rapid temperature changes will help keep the Integrator signal stable. If the feedback is working OK, it can be turned off and the sensor board removed.

(3) Check the boom oscillation period, which will initially be too short.

(4) Increase the boom oscillation period by shortening the spring very slightly. Add trim mass to balance.

To achieve balance small washers or other non-magnetic objects can be temporarily added to the trim mass. For small corrections the thumb nut(s) can be adjusted slightly.

Shortening the spring will lengthen the oscillation period, up to the point that the boom becomes unstable and sticks at either its upper or lower limit of motion. If that happens, lengthen the spring a little. Shortening the spring too much, resulting in too flat an arch, can stress the spring to the point that it becomes permanently curved. When shortening the spring, go slow.

Repeat from (3)

(5) When you achieve a decent oscillation period of 3 seconds or so, construct a permanent trim mass which matches the weight of the temporary mass, put it in place and if it is correct, the boom can be exactly balanced by a slight adjustment of the thumb-nuts.

(6) Re-install the sensor board, and after making sure the base plate is accurately leveled, turn on the feedback electronics and monitor the integrator (Centering Force) output signal. Adjust the thumb nuts slightly so that after it settles (a few minutes) the integrator output reads near zero Volts.

Now put a spacer with thickness from 0.1" to 0.25" under each of the adjustable legs to tilt the instrument a few degrees in one direction and after it settles record the integrator output. Remove the spacers and place one of them under the fixed leg to tilt the base an equal amount in the opposite direction and note the integrator output voltage. The integrator signal should reach a maximum when the base is level and should go negative by an equal amount when tilted equally each side of center as in Figure 1. If that is not the case as shown in Figure 2, raise or lower the trim mass until it does.

(7) Final balance is achieved with the instrument sitting level by adjusting the thumb-nuts until the Integrator output is near zero. Note that this is something of a moving target, as the integrator signal varies quite a bit with temperature, or more precisely, with the rate of temperature change.

If necessary, thumb nuts could be added or removed to get the boom to balance although that will slightly change the height of the boom's center of mass and you should re-check the adjustments from step (6).

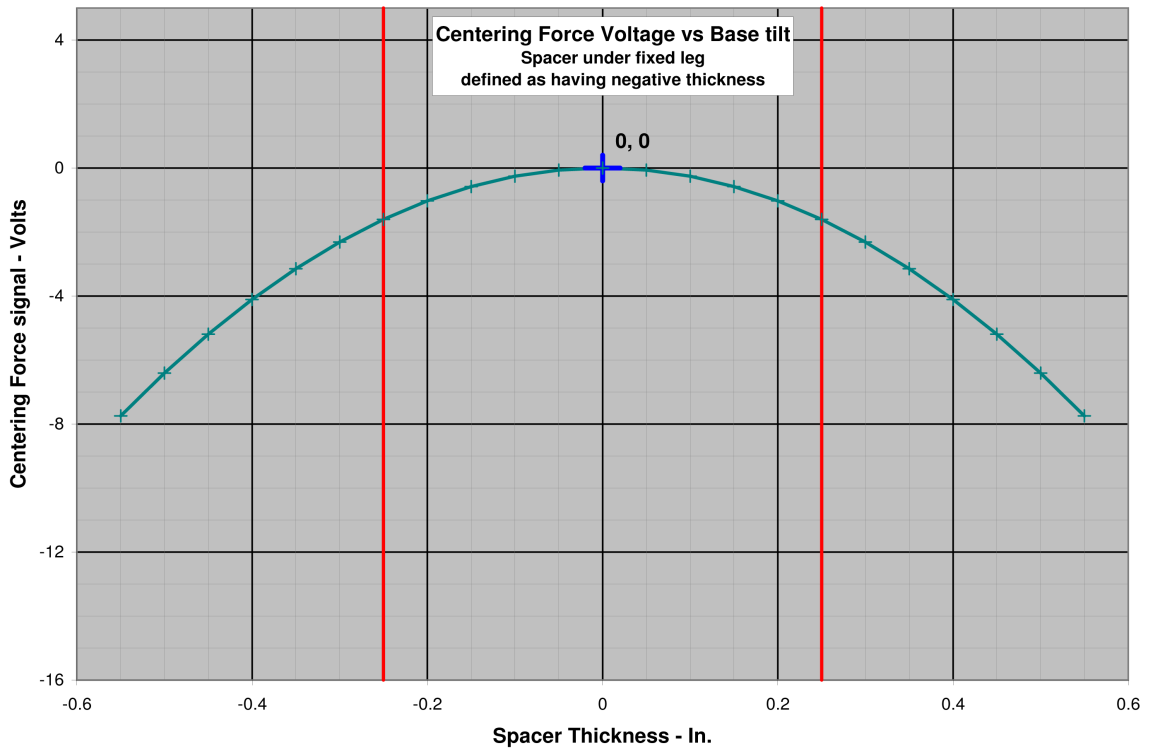


Figure 1.
Sensitive axis accurately vertical

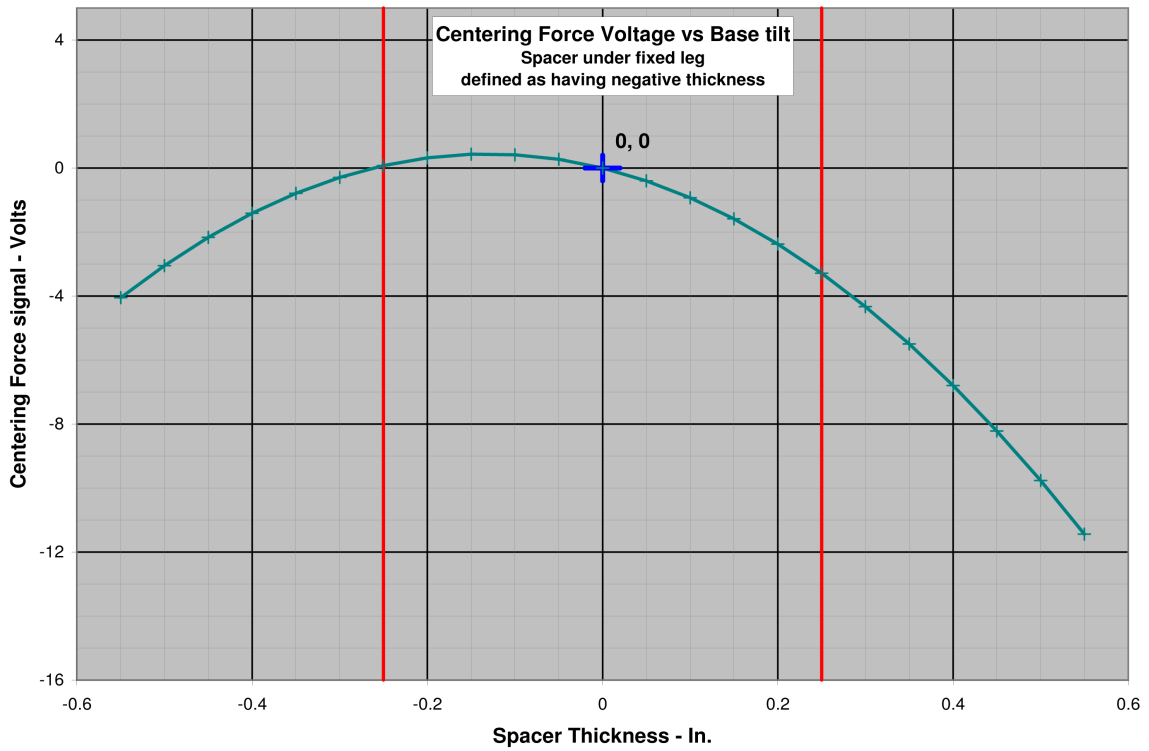


Figure 2.
Sensitive Axis 1 degree off vertical
Trim weight too high

What's happening?

Making the suggested adjustments changes the mechanical parameters of the boom-spring system in the following ways:

- 1) The boom comes to rest in a horizontal position.

The net restoring torque curve for the system crosses zero when the boom has zero degrees of rotation, that is, when it is horizontal. Fig. 3

This is accomplished by changing the magnitude of the trim mass, thus changing the total boom weight, and in the final stages by slightly adjusting the horizontal location of the boom's center of mass using a horizontally-moving thumb nut(s).

- 2) The free-oscillation period is reasonably long--3 seconds or so.

The slope of the net restoring torque curve is sufficiently low, making for the desired long oscillation period. Fig. 3

This can be changed by adjusting the length of spring between its clamps. Each time this is done the trim mass or its horizontal position will have to be adjusted slightly to re-balance the boom.

- 3) The instrument has little or no sensitivity to horizontal motion, i.e. its sensitive axis is nearly vertical.

The location of the boom's center of mass is in the same horizontal plane as the pivots.

This is adjusted by varying the height of the trim mass.

- 4) Free-oscillations are symmetrical about the boom rest position, in particular, having no tendency to stick at either limit stop.

The slope of the net restoring torque curve should be relatively symmetrical about zero degrees boom rotation (level boom) and should remain negative and relatively linear throughout the boom's entire range of motion. Figures 3, 4 This is equivalent to the condition that the free oscillation period be substantially independent of the boom position.

This is mostly determined by the geometry of the boom, that is, by the relationship between the location of the pivot, the boom's center of mass and the spring attachment points and also by the total boom mass and the characteristics of the spring. If the original design is followed reasonably closely, this will come out right when all the other adjustments are correct.

Net Pivot Moment vs Boom Angle
L = 3.4600 in

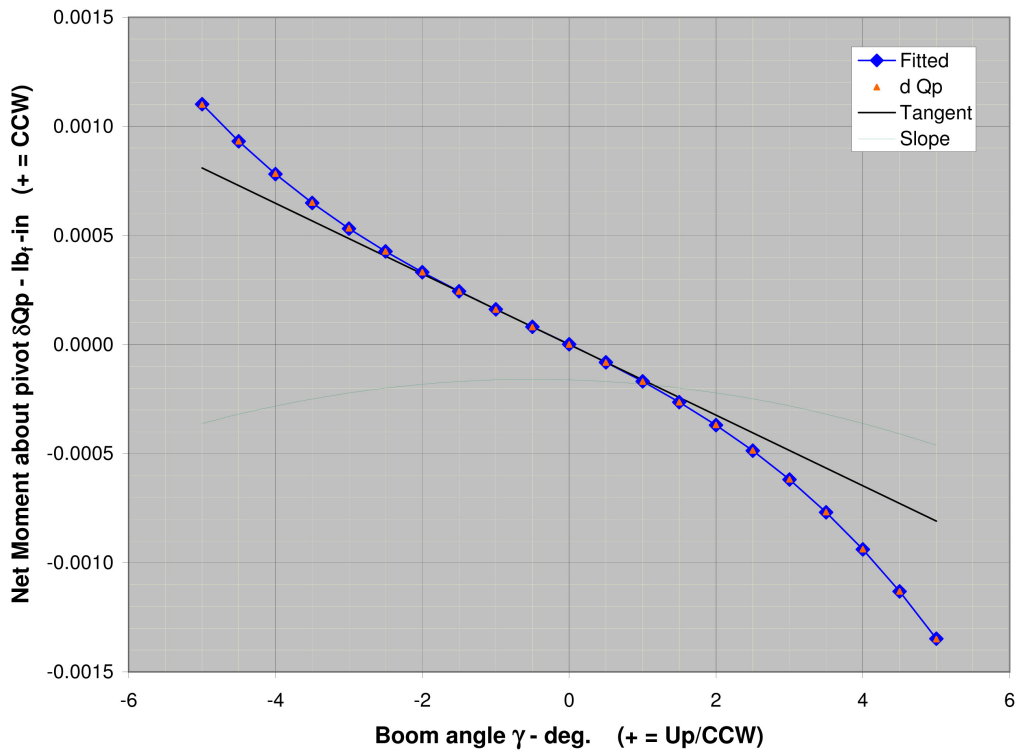


Fig. 3 - Well-designed geometry

Net Pivot Moment vs Boom Angle
L = 3.4800 in

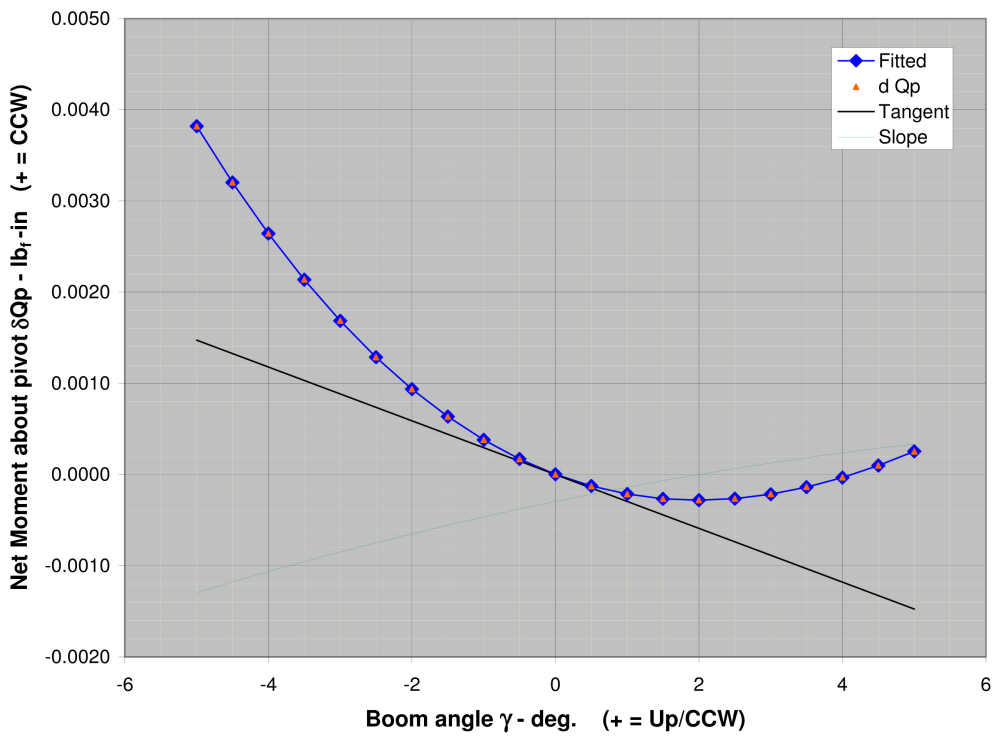


Fig. 4 - Bad geometry design
 Poor linearity

Will flip to the upper limit when the boom is tilted above +2 deg.

Appendix 1

Erhard Wielandt's comments on making mechanical adjustments.

Adjusting a leaf-spring pendulum August 2005

E.W.

Conditions (priority depending on the application):

- The mass must be balanced, i.e. in equilibrium with the spring force
- The axis of sensitivity must be vertical (equivalent: the center of gravity must be in a horizontal plane with the hinges)
- The free period must have the desired value (it is virtually infinite in Streckeisen seismometers)
- The free period should be constant (independent of the mass position)
- The base plate should be horizontal when the above conditions are met, so that the sensor can later be levelled with a bubble level

Adjustments: work out a logical order of these adjustments for yourself – adjustments that change only one property are made last! The pendulum must be rebalanced after each adjustment.

- Adding or removing parts of the mass → will establish equilibrium, but may change period and sensitive axis
- Adjusting a horizontal slug screw, or moving parts of the mass horizontally → affects only the equilibrium
- Adjusting a vertical slug screw → will change sensitive axis and period
- Adjusting the zero position of the displacement transducer → will change the sensitive axis and nothing else. This is the only adjustment changing the position of the pendulum against the frame (may not be desirable).
- Adjusting the length of the spring, or the position of a spring clamp → will change equilibrium, period, linearity (constancy of the period)
- Adjusting a spring clamp in two directions, or in one (suitable) direction when the spring length is also adjusted → will change equilibrium, and independently adjust period and linearity. Consult the 'leaf5' program for directions.
- Tilting the whole instrument → changes axis, period, baseplate levelling.

Determining the sensitive axis:

You must use force feedback to keep the pendulum in a fixed position with respect to the frame. Then observe the feedback current as a function of tilt in two directions. The tilt position where the current has an extremum defines the vertical position of the sensitive axis. In order to make this position coincide with the horizontal position of the base plate or of any other reference surface, you must change the center of gravity with respect to the frame. This can be done either with a vertical slug screw or by changing the zero position of the displacement transducer.

Appendix 2

One procedure (of several) used by Dave Nelson:

Hang boom assembly vertical w/o trim mass

Determine what moment is needed to balance vertically.

Mount Boom

Spring loose

Put under-sized trim mass in place & adjust spring for balance

Measure period which will be too short.

Shorten spring and add mass for balance.