Mechanical Setup for the FBV Seismometers

Brett Nordgren
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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 weight of the trim masses
2) the spring length between its clamps
3) the horizontal location of one trim mass
4) the vertical location of the other 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.

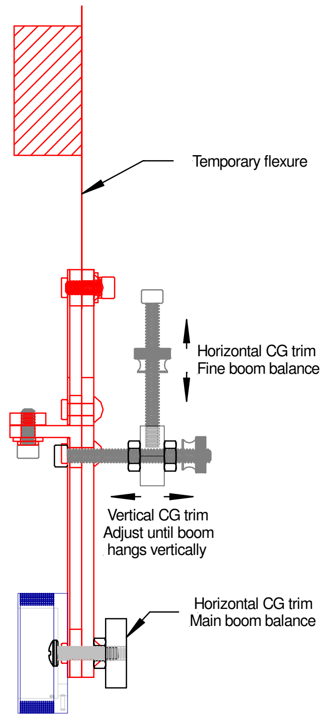
Note that the adjustment of the spring length between the clamps is extremely sensitive. A change in clamp position of a few thousandths of an inch, makes a significant change to the free period.

Rough adjustments to the boom balance may be made by adding or removing small brass or aluminum washers to the boom at the coil location However, it may be adjusted slightly by means of one or more thumb-nuts riding on a horizontal screw, which acts as a secondary trim weight. The vertical location of the center of mass is adjusted by another trim weight which moves on a vertical screw.

Procedure

(1) Adjust the vertical Center of Mass:

With the boom removed from the instrument, without the spring, but with all hardware including the trim weight present, clamp two temporary long flexures extending out from the rear of the boom. Since the flexures are temporary, they could be made of any flexible material, even printer paper. Attach the temporary flexures to a flat vertical surface and allow the boom to hang freely.



Then, adjust the vertical trim weight until the boom hangs exactly vertical. If the weight ends up near the boom surface, it can be made lighter, or if it must be far from the boom, a slightly larger mass may be indicated. Ideally it should be near the center of its adjustment range when balanced. And I might put a thumb nut on the vertical screw in order to simplify any fine tuning required later. The design above which has a clearance hole in the vertical trim mass, using two nuts to adjust its position will allow the horizontal fine trim screw to continue to face the pivot during vertical adjustments. I believe that the horizontal trim screw must point towards the pivot, as shown, so that it won't interfere with the electronics board.

On at least one occasion, with a large mass located near the end of a long screw, it was suspected that a mechanical resonance was created which had the potential to cause feedback oscillation. In that case, a larger diameter, stiffer, screw might have been helpful.

(2) Install the boom, flexures and spring. With the electronics turned off and the sensor board removed, set the horizontal thumb-screw(s) to the center of their adjustment range. With the base plate leveled, slowly shorten the spring length until the boom is approximately balanced.

(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 temporary trim mass at the coil to balance. Dave uses pennies or small brass washers.

> 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 on the coil and if it is correct, the boom can be exactly balanced by a slight adjustment of the thumb-nuts.

(6) At this point the sensor board can be installed, the coil hooked up 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 horizontal trim thumb nut. Shielding the instrument from drafts and rapid temperature changes will help keep the Centering Force signal from drifting too rapidly. Adjust the horizontal thumb nut slightly until the Centering Force signal settles near zero Volts

(7) Fine tune the vertical CG location.

After checking that the base is level, record the Centering Force voltage. Then put two identical spacers with thickness from 0.1" to 0.25" under the two adjustable legs to tilt the instrument a few degrees in one direction and after it settles, again record the Centering Force 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 CF output voltage. Enter the data into the 3_Points sheet of Tilt-Test_357.xls workbook, entering the spacer thickness under the fixed leg as a negative value. Chart 3 will show how close it is to ideal. That signal should reach a minimum when the base is level (or a maximum if the instrument polarity is inverted due to reversed coil and sensor plate connections), and it should change by roughly the same amount when tilted equally each side of center as in Figure 1. If that is not the case as shown in Figure 2, change or raise or lower the vertical trim mass or fine trim nut until it does. Note that if the vertical trim mass weight is changed, the horizontal mass will have to be changed to maintain balance. A more precise measurement can be made by using two or three spacer thicknesses and plotting 5 or 7 points.

(7) Final balance is achieved with the instrument sitting level, by adjusting the horizontal thumb-nut(s) until the Integrator output is near zero. Note that this is something of a moving target, as the Centering Force voltage varies with temperature, or more precisely, with the rate of temperature change.

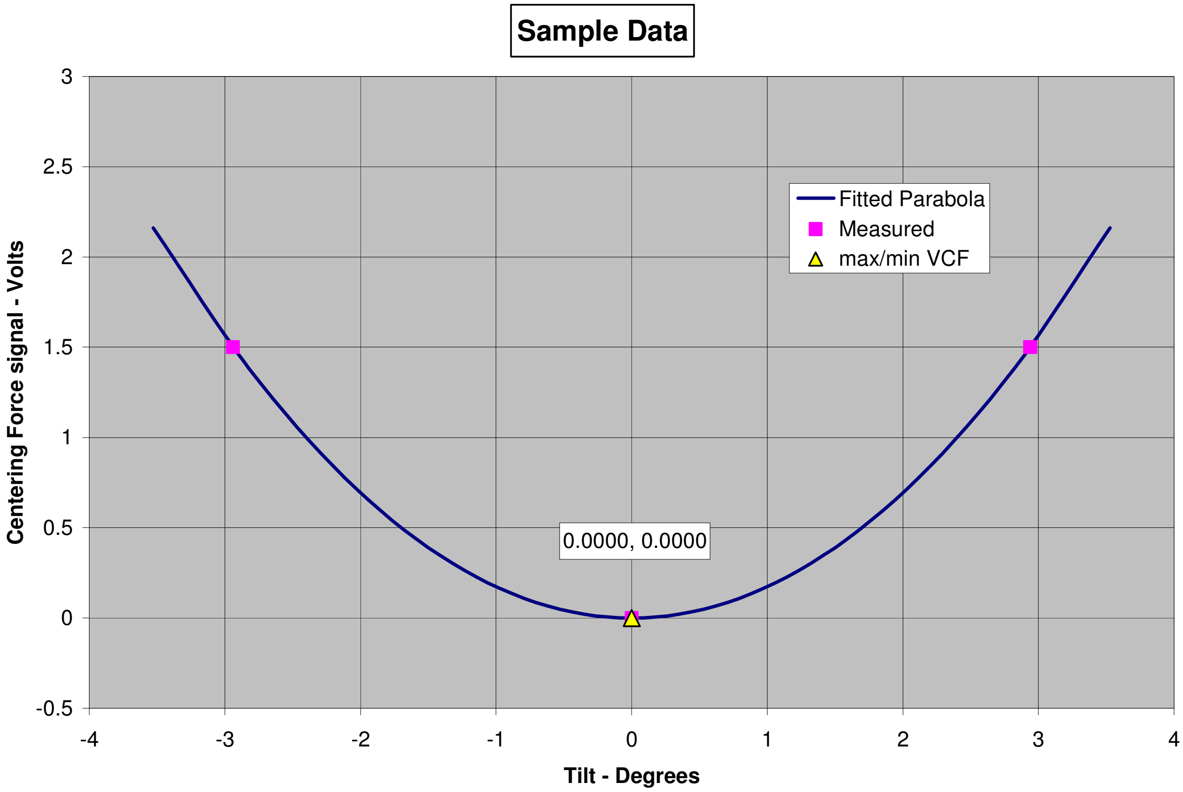


Figure 1.
Sensitive axis accurately vertical

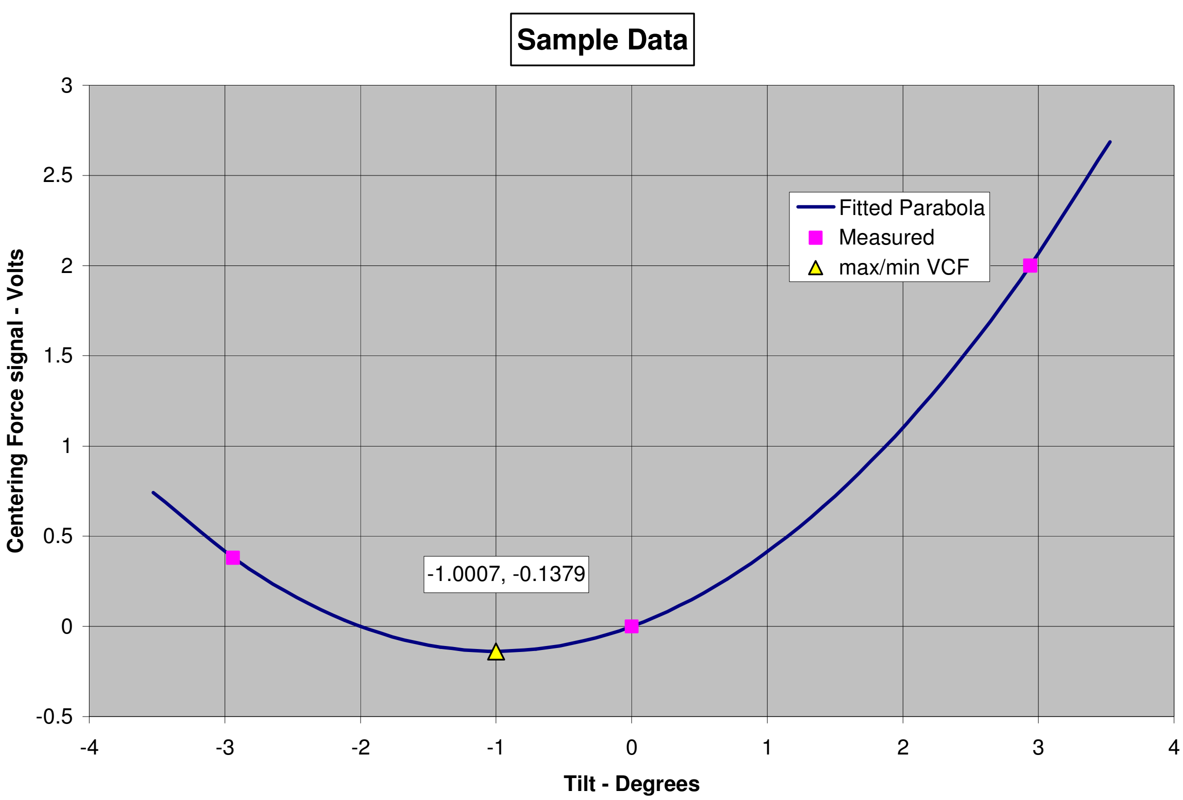


Figure 2.
Sensitive Axis 1 degree off vertical
Trim weight too high

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 restoring torque curve for the astatic spring system crosses zero at the point where the boom has zero degrees of rotation, that is, when it is horizontal. Fig. 3
>
> This is accomplished by changing the amount of horizontal 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 goal of having a long free period is to adjust the astatic spring system to create a restoring torque curve with a sufficiently low slope. Fig. 3 The lower the slope, the easier it is for the feedback loop to control the boom motion. Ideally, we would like it to have infinite free period, but 3 seconds can be readily measured and is entirely adequate.
>
> The free period can be changed by slightly changing the length of spring between its clamps. Each time this is done the amount of horizontal trim mass or its position will have to be adjusted 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 its pivots. This is adjusted by varying the height of the vertical trim mass.

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

> The slope of the boom's restoring torque curve should be relatively symmetrical about zero degrees of 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 precise relationship between the location of the pivot, the boom's center of mass and the spring attachment points and 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 the other adjustments are correct.

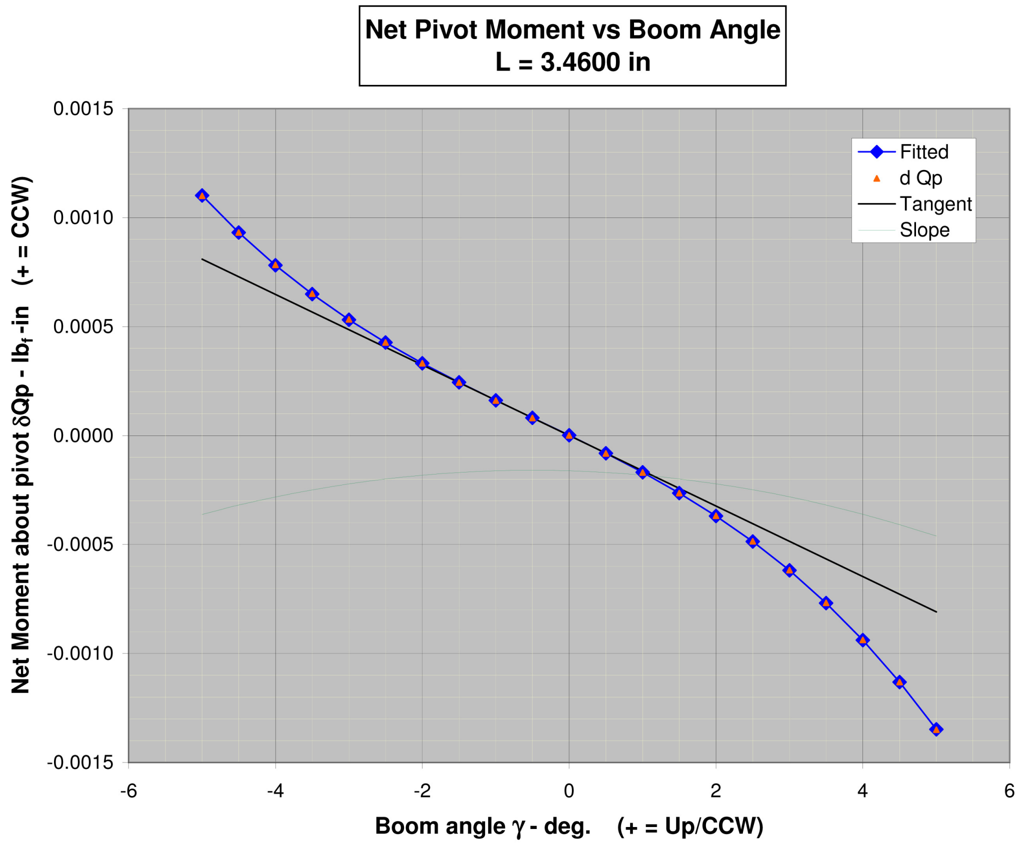


Fig. 3 - Well-designed geometry

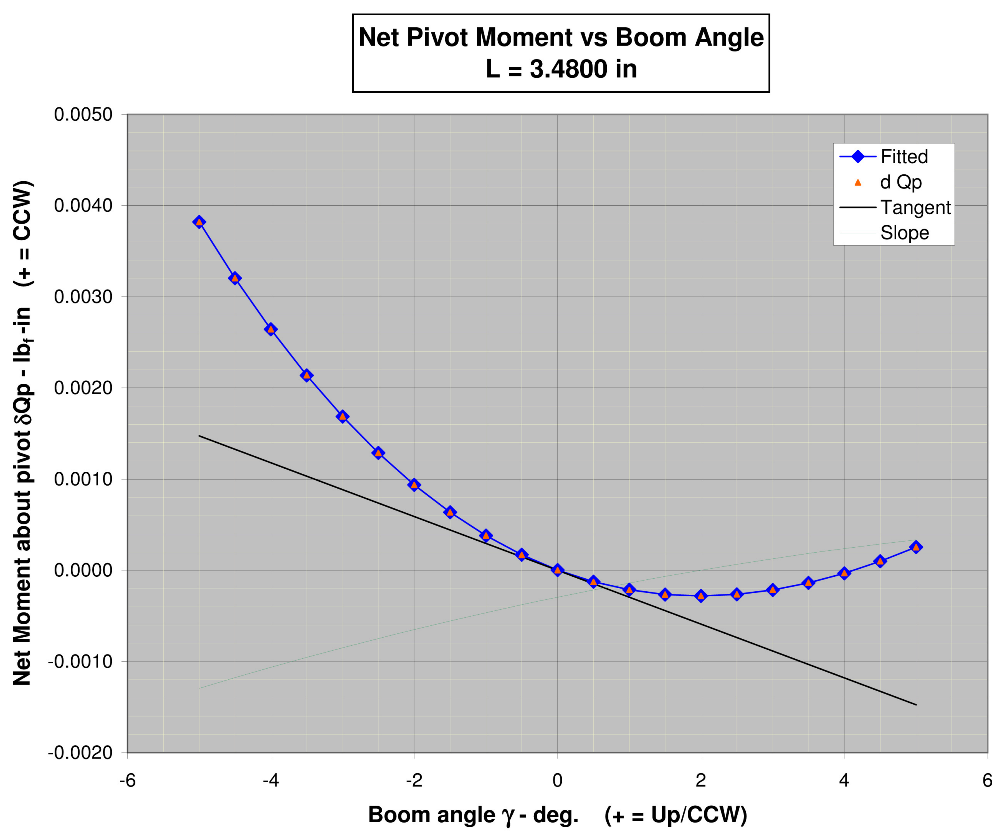


Fig. 4 - Bad geometry design

Poor linearity

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

Appendix 1

Erhard Wielandt's comments on adjusting a commercial seismometer.

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.