Automated field testing of 3-C geophones using a 3-C microvibrator

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ABSTRACT

Existing techniques for determining the 3-component (3-C) geophone orientation, channel assignment, and polarity in land seismic surveys are problematic. The current technique of tap testing is fraught with difficulties due to the large amount of human intervention required to successfully perform the test in the field. Additional problem frequently occur as a result of poor communication of field test results to the seismic data processor. An apparatus is proposed to solve this problem. It uses three orthogonally oriented, rotating microvibrators to form a 3-C microvibrating source. After performing an automated field test, the data are passed through a simple processing flow. The output of that processing flow can be used as the basis of an automatic orientation and polarity determination system. A prototype 3-C microvibrator was constructed and its output is recorded with a 3-C geophone. A field test indicates that the technique shows promise, but refinements are necessary in order to produce a robust, automated solution.

INTRODUCTION

Three-component seismic recording is often complicated by problems in recording and communicating the geophone orientation, the element wiring sequence, and the geophone channel assignment. Though tap testing can be a valuable aid in providing the necessary ground truth, tap tests are frequently fouled-up, and many three-component processors find them too untrustworthy to be of any value. Tap tests may be fouled-up for a number of reasons:

- Incorrectly following the tap test procedure (tapping east-to-west instead of north-to-south)
- Non-transmittal of the observer's notes associated with the tap test
- Incorrect recording of the tap test (using a different channel assignment pattern for the tap test than is used for a production shot record)
- Poor quality tapping -- taping with a hard object can create tap tests which have frequencies which exceed the recorder's frequency bandwidth
- Incorrect interpretation of the tap test due to inappropriate trace plotting parameters

This paper proposes a new apparatus and processing flow designed to replace standard 3-C tap tests. Together, these provide the required ground truth for determining the hookup and orientation of 3-C geophones.

APPARATUS

A 3-C microvibrator

A 3-C component vibrating device may be constructed using three eccentric-mass vibrating motors oriented orthogonally to each other.

FIG. 1. Small vibrating motors (a dime is shown for scale) produce a two-component sinusoidal vibratory source. These motors are typically used in vibrating mobile telephones and pagers.

As each mass rotates, the vibrator creates a rotating force vector F, which may be resolved into two orthogonal forces F_x and F_y.

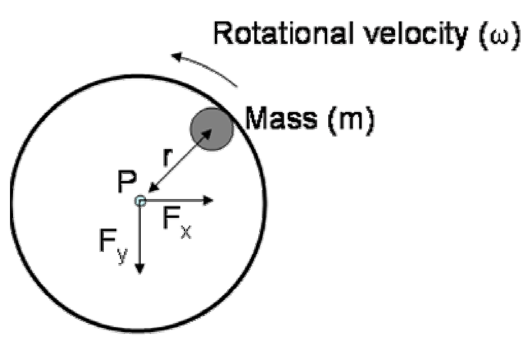

FIG. 2. An eccentric mass rotates about a point P at a distance r generating sinusoidally-varying forces F_x and F_y.

The magnitude of the force is determined by

$$F = m\omega^2 r \tag{1}$$

where m is the mass of the eccentric object, ω is the rotational velocity, and r is the radius of rotation. The force may be resolved into two orthogonal force vectors:

$$\begin{aligned} F_x &= F \sin \omega t \\ F_y &= F \cos \omega t \end{aligned} \tag{2}$$

To form a 3-C microvibrator, three motors are embedded in a cube as shown in Figure 3.

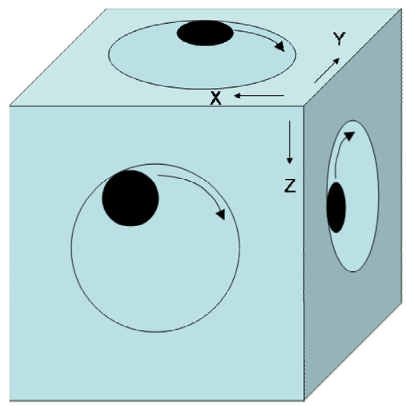

FIG. 3. A three-component vibrating cube incorporates three eccentric-mass vibrators arranged orthogonally. Each vibrator generates motion in two axes.

Figure 4 shows the theoretical response from three orthogonally-positioned geophone elements when acted upon by three orthogonally positioned disc vibrators. Each of the three motors is switched on, then off in sequence.

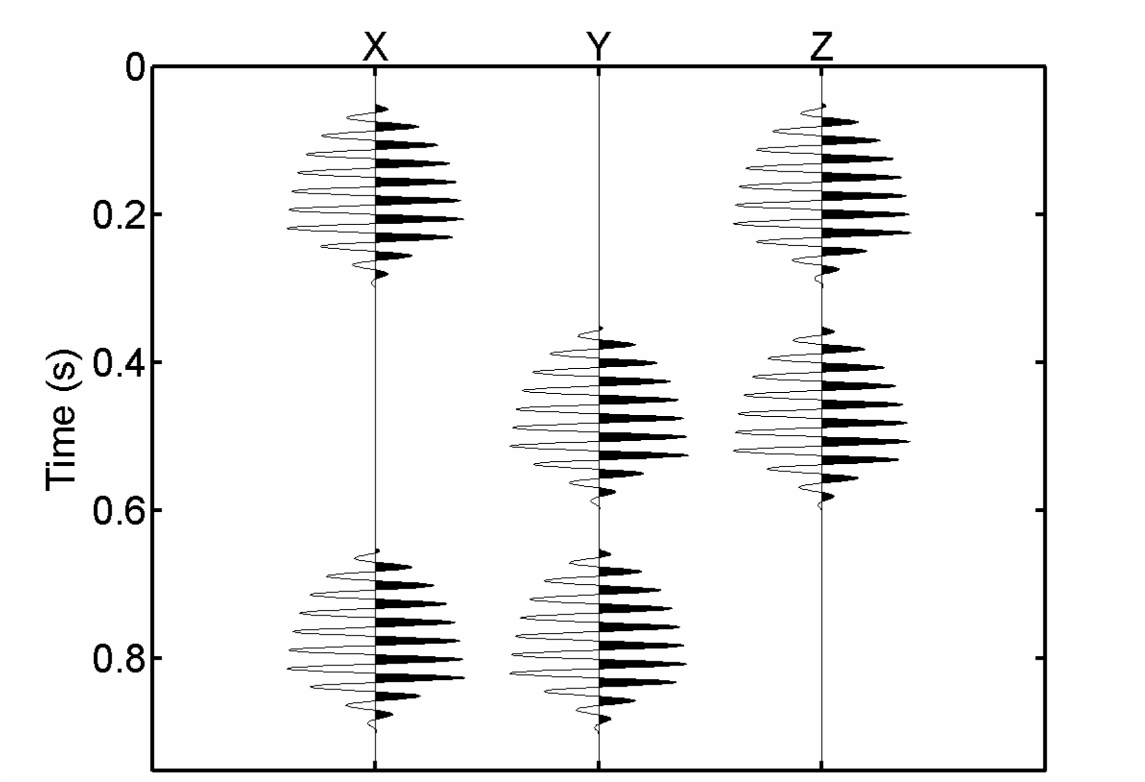

FIG. 4. Theoretical response to the switching on and off of three vibrating disc motors in sequence is shown. Here the motor on the Y=0 plane is activated first, the X=0 plane second, and the Z=0 plane motor third. The amplitude envelope mimics the envelope observed on some test motors. In this example, the motors spin at 40 Hz (2400 RPM).

A geophone testing device using a 3-C microvibrator

Tap testing a geophone generates a vector pulse in one direction at a time. Analysis of the three output channels of a geophone yields the channel assignment and polarity. By contrast, the rotating microvibrators excite two axes at a time. Rather than look for the presence of signal, one can use the absence of signal as an indicator of the unique element which is inline with a microvibrator's rotational axis. Figure 4 illustrates this property.

The proposed geophone testing device includes a 3-C microvibrator placed at the end of a staff. In the field, the staff is planted directly beside a geophone under test. The staff is then rotated so that it is oriented toward a known position: either magnetic north, by way of a compass on the top of the staff, or by pointing the staff toward the end-of-line station. Though it is preferable to orient the staff toward magnetic north (requiring no judgment from the operator), doing so increases the likelihood that the geophone elements will be oriented at an irregular angle to the vibrator elements. This is not an insurmountable problem many robust algorithms exist to back-out any azimuthal rotation angle (Disiena, 1984). Our discussion and examples will always assume that the geophone under test has its elements aligned with the axes of the 3-C microvibrator.

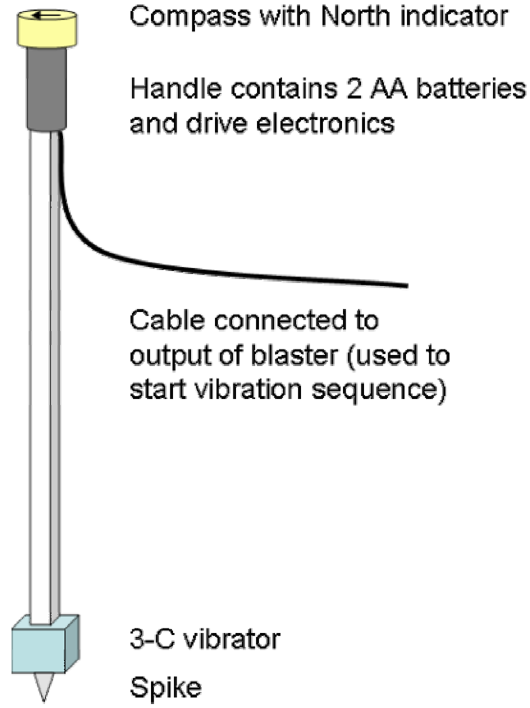

FIG. 5. A staff-mounted 3-C microvibrator shakes the ground beside a geophone. Batteries and electronics in the handle energize each disc vibrator in sequence. A spike on the bottom of the staff improves the coupling of vibratory energy to the ground.

The ideal apparatus would allow precise recording of the vibrating motor's position along with the received signal from the geophone. In theory, a pilot channel could be used to record the angular position of each motor throughout the vibration sequence. Since only one motor spins at a time, only one channel would be required. Geophone element polarity could then be determined by comparing the recorded polarity with one computed from the pilot channel. One feasible way to operate the system would be to connect the 3-C microvibrator to a dynamite blasting box: the blaster would trigger a sequence of motor movements, and the pilot trace would be connected to the blasting box's uphole phone input.

Another possible operating mode (perhaps a better one), has no connection between the 3-C microvibrator and the recorder. In this operating mode, the 3-C microvibrator emits a known vibration sequence repeatedly. If the sequence has an easily discernable beginning and end, the recorder only needs to record a time window that is long-enough to include the full sequence. If the motors are under sufficient control that their rotational position can be manipulated precisely, using stepper motors or servo motors for example, then it may be possible to entirely eliminate the need for a pilot channel.

Polarity determination

There are properties of rotating vibrators which may assist in determining the polarity of the elements of a geophone. As the eccentric mass rotates, there is a quadrature pattern which indicates the rotational direction of the motor. If one axis is of opposite polarity, the pattern will change. We can use this to help to identify the polarity of geophone elements.

Table 1. Quadrature signature of a rotating microvibrator

Rotation angle (degrees)	X-axis output	Y-axis output
0	0	1
90	1	0
180	0	-1
270	-1	0

If a single geophone element is reversed, the quadrature pattern is altered, and the reversed element is detected.

A method for determining polarity

If we view the output of two geophone elements placed in the plane of rotation of a rotating vibrator, we can see that they each record sine waves. The two sine waves differ in phase by 90 degrees. For a given pair of traces *x(t)* and *y(t)*,

$$\begin{aligned} x(t) &= a\cos\omega t \\ y(t) &= a\sin\omega t \end{aligned} \qquad \text{(3a, 3b)}$$

To determine the polarity we multiply *x(t)* by *y(t)* after phase shifting *y(t)* by 90 degrees (so that the lobes of the sine waves line-up). Since we are working with sinusoids, we can differentiate *y(t)* with respect to *t* to obtain the necessary phase shift. Simple numerical differencing of adjacent trace samples accomplishes this nicely. We can express this as

$$\frac{\partial y(t)}{dt} = a\cos\omega t \qquad (4)$$

or in discrete terms as

$$\text{dy(i)} = \text{y(i+1)-y(i).} \qquad (5)$$

If we multiply *x(y)* by $\partial y(t)$ we get

$$x(t)\partial y(t) = a^2\cos^2\omega t\ , \qquad (6)$$

which is a positive expression for all values of *t*. If there is a phase rotation then

$$x(t)\partial y(t) = -a^2 \cos^2 \omega t\,, \qquad (6)$$

and the result is negative for all values to t. Therefore the sign of $x(y)\,\partial y(t)$ is a clear indicator of a polarity reversal. We can apply this technique to all other pairs of traces to determine the polarity of all traces. Figure 6 shows the trace products after rotating one phase by 90 degrees. Figure 7 shows the same trace products in the event of a single polarity reversal. Unfortunately the product of the two traces may yield positive or negative results as a result of two different polarity reversal scenarios. We must therefore always have a method of knowing the absolute polarity of at least one geophone element using a different polarity determination technique.

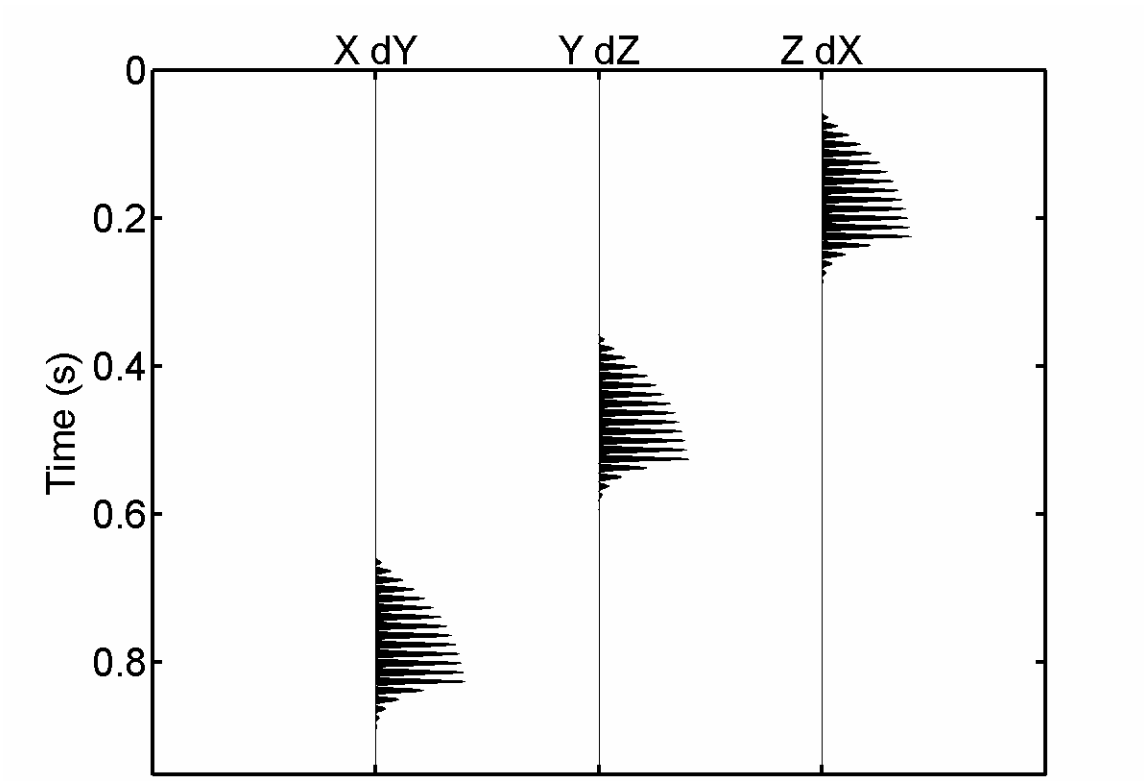

FIG. 6. The synthetic data traces from Figure 4 are processed to detect polarity reversals. Here, trace excursions are exclusively positive because there are no trace polarity reversals.

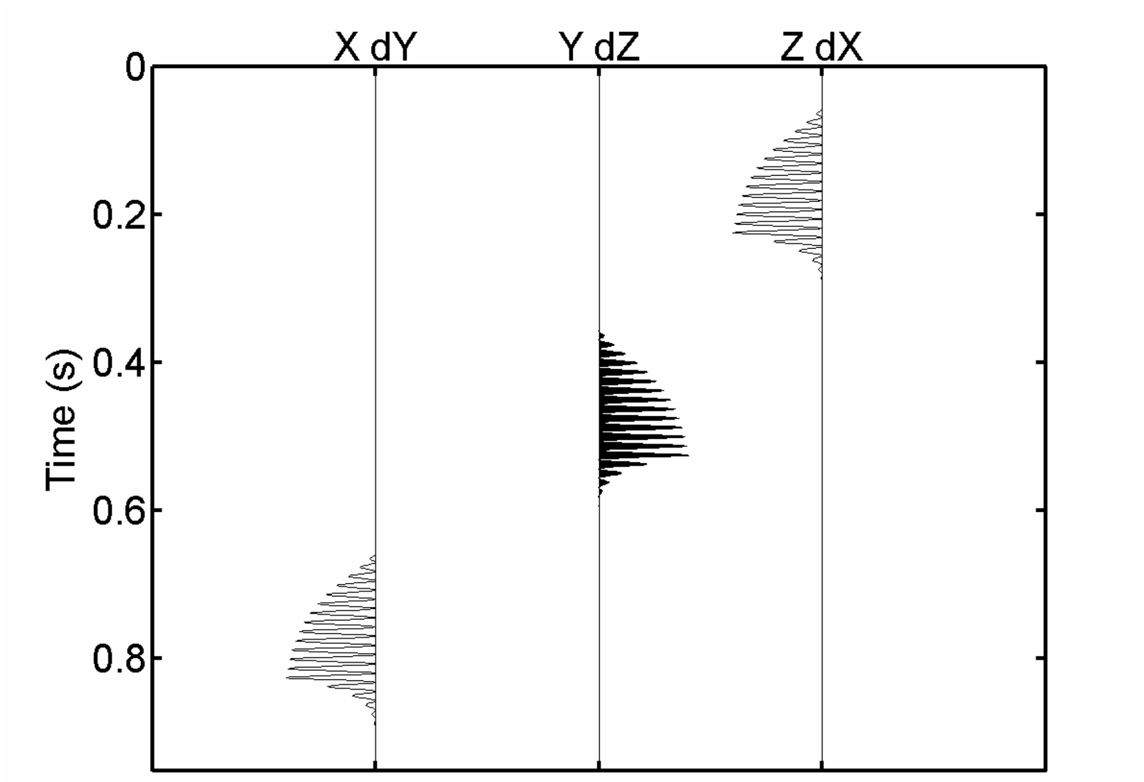

FIG. 7. If the X trace has its polarity reversed, the resultant traces are directed negative whenever the polarity-reversed trace is involved in the calculation.

By introducing 25% crosstalk into the synthetic seismic dataset we can see the effect of crosstalk on the processing flow (Figure 8).

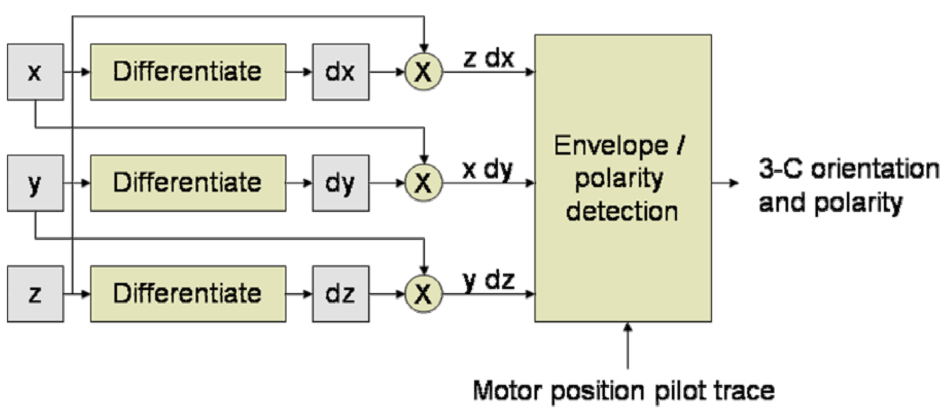

FIG. 8. Block diagram of processing flow to determine 3-C orientation and polarity.

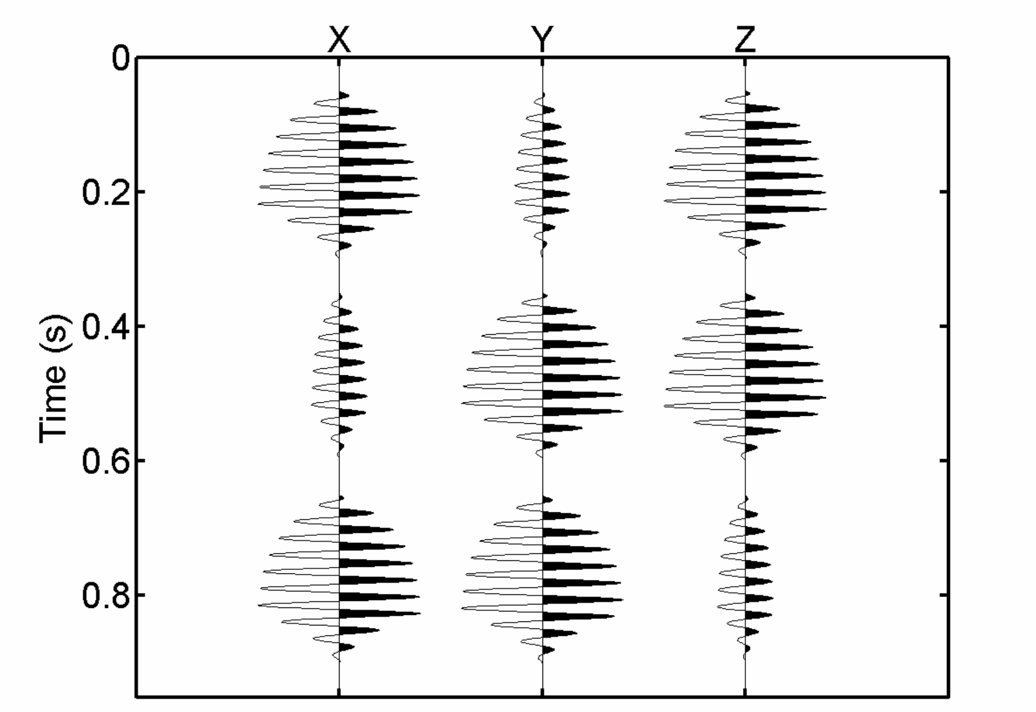

FIG. 9. Crosstalk is added to the ideal (synthetic) data generated by a 3-C microvibrator.

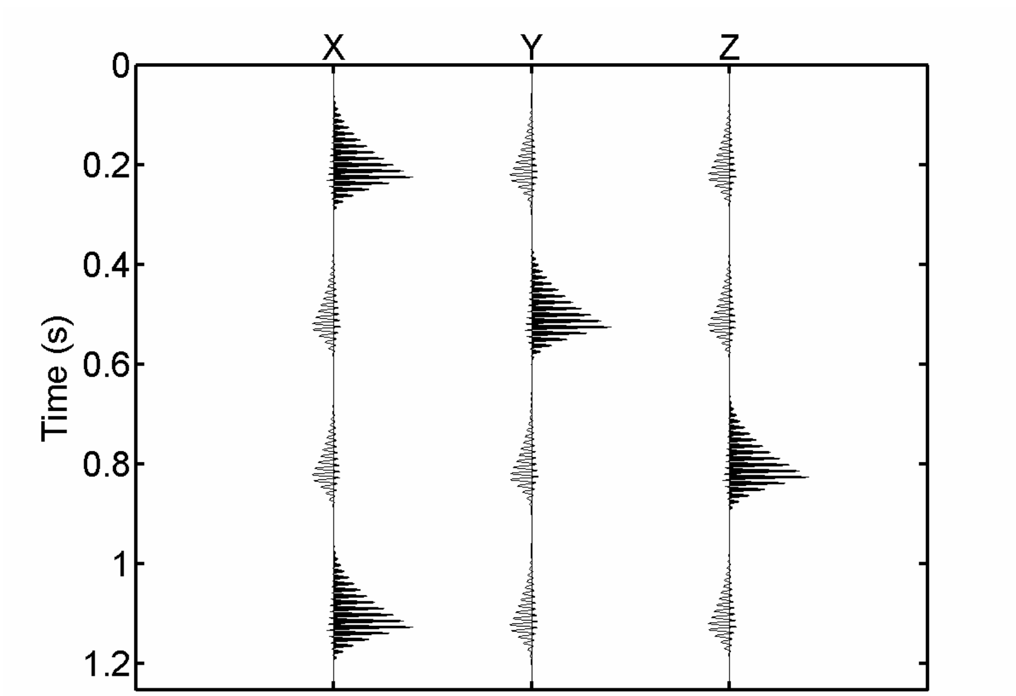

FIG. 10. Processed output of the synthetic data with 25% crosstalk shows how the crosstalk is largely rejected by the procedure.

Results from a 3-C microvibrator prototype

A prototype 3-C microvibrator was constructed using three rotating disc motors (Figure 11). Each motor was glued to the face of a small wooden block approximately 3cm per side. The three motors were wired to a battery via a 5 position switch (Figure 12). In the first and last switch positions, the motors are all switched off. The three middle positions turn on each of the three motors in sequence (one at a time). By turning the switch through its 5 positions, each motor was energized in sequence for a short period of time (approximately 200ms). The block was place on the ground beside a 3-C geophone and held in place (by hand) throughout the test. The experiment was performed in realistic conditions: The equipment was setup outdoors and the geophone and 3-C microvibrator were planted in grass-covered, unfrozen ground. Figure 13 shows the data acquired by the adjacent geophone.

Experimental results show that the vertical channel receives significantly less vibratory energy (approx 3.4 dB) than the two horizontal channels. The traces in Figure 13 were amplitude-equalized before processing. One possible explanation is that the hold-down force prevents motion of the 3-C microvibrator in the Z axis direction. Since the 3-C microvibrator is unconstrained in the horizontal directions, more horizontal motion is generated than vertical motion.

FIG. 11. Prototype 3-C microvibrator.

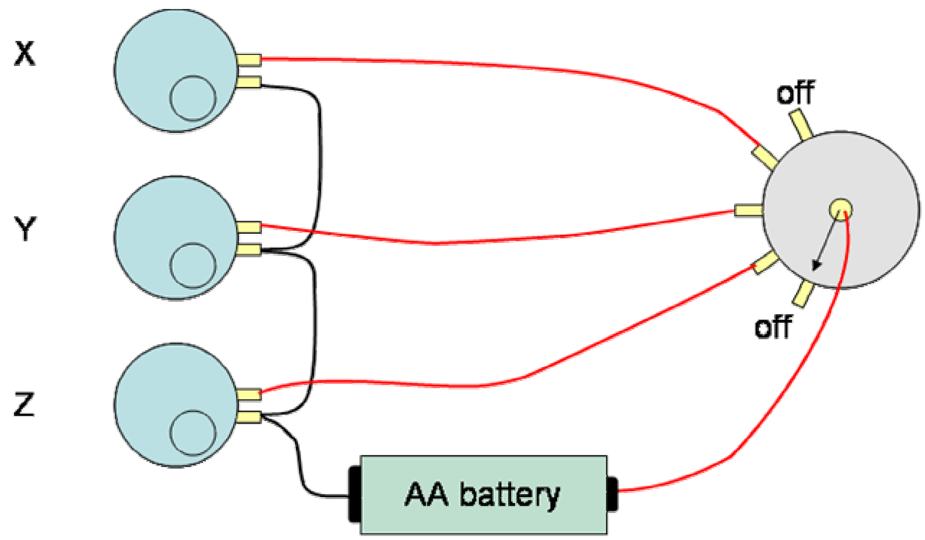

FIG. 12. Three motors are operated in sequence by connecting them to a battery via a rotating selector switch.

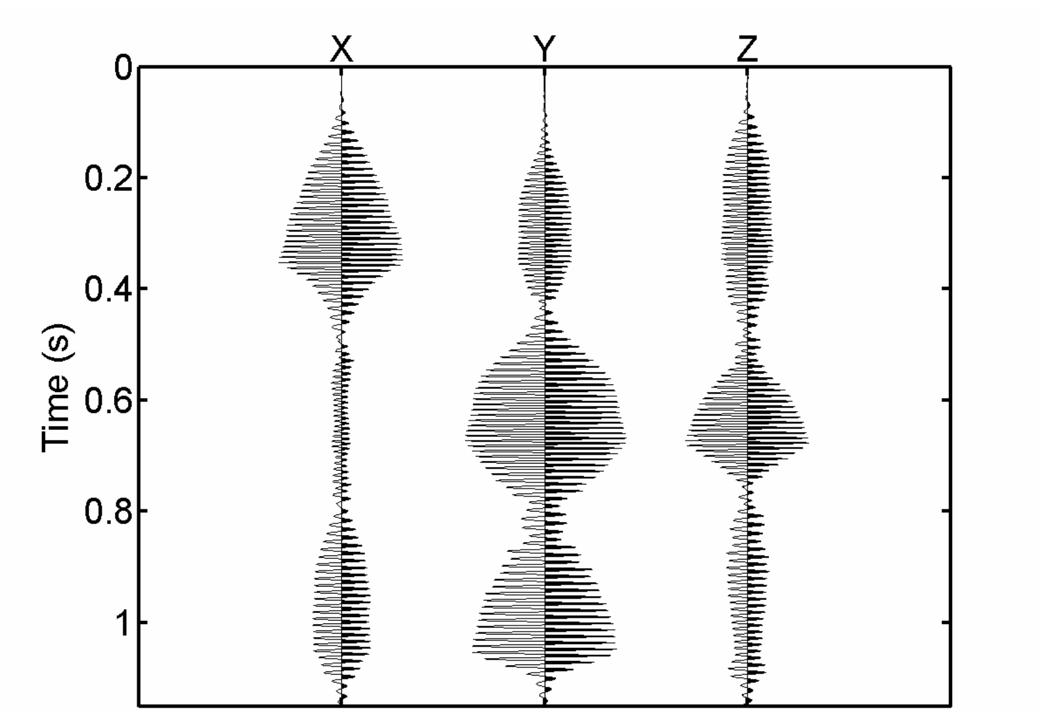

FIG. 13. Output of the prototype 3-C microvibrator recorded by a 3-C geophone. The motors were activated in sequence (Y=0, X=0, Z=0) for a brief period of time.

The vibrating motors used for the prototype rotate rather quickly, generating a sine wave at a frequency of approximately 200 Hz. This frequency is close to the geophone's 160 Hz spurious frequency, so there is the possibility that resonances internal to the geophone element are tainting the received signal. At the time of writing, no higher-frequency geophones were readily available, and no lower frequency motors were available for testing. In ongoing experiments we shall repeat these tests with a better frequency match between the geophone and 3-C microvibrator.

We can see that the results succeed in indicating the vibratory sequence, though not as conclusively as one would like. It would appear that there is poor vector fidelity in the 3-C microvibrator, as a great deal of rotational energy appears on the element inline with the axis of rotation (which should be silent). It was observed that the 3-C microvibrator wobbled while it rotated. Since the microvibrator cube was held in place with a finger, it was difficult to damp the wobbling. Attachment of the microvibrator to a firm staff should help reduce this wobbling effect and produce an output which is more pure.

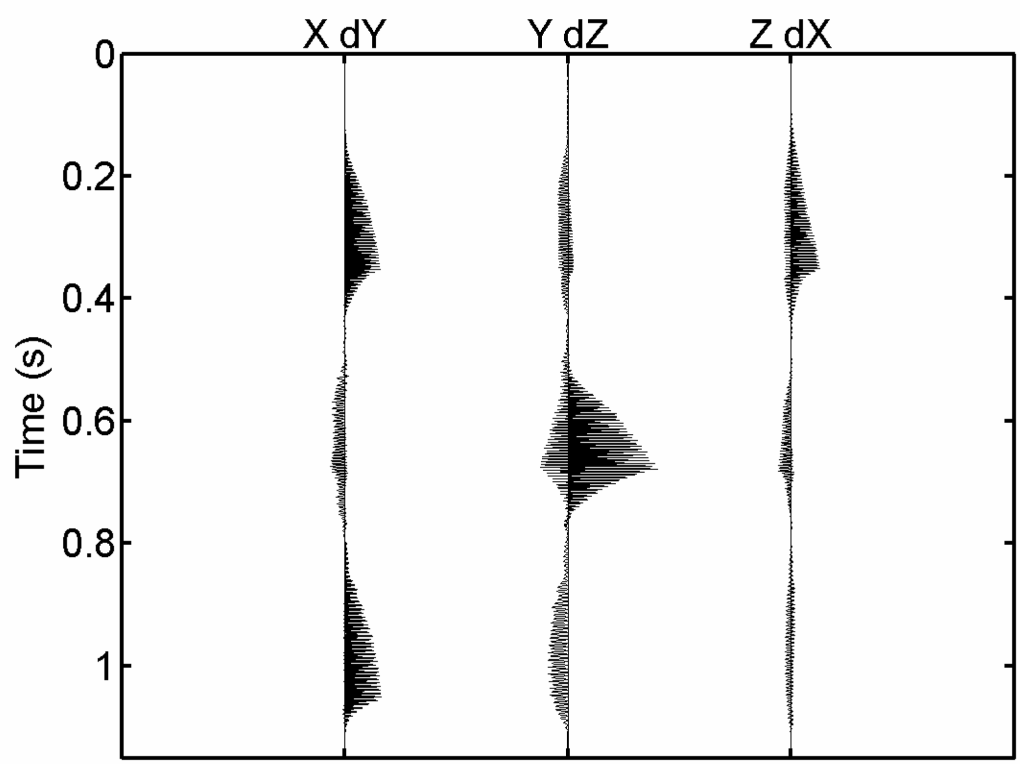

FIG. 14. Output of the differentiation and multiplication stage of the processing flow is shown. Between 0.2 and 0.4 seconds, the Y=0 motor is vibrating, and the Z dX trace has a high amplitude lobe. Between 0.5 and 0.8 seconds the X=0 motor is vibrating and the Y dZ trace reflects this nicely. Between 0.9 and 1.2 seconds the Z=0 motor is vibrating, and the peak lobe is on the X dY trace. Although the first of the three vibrations is inconclusive, the second two are not. One can therefore deduce that the first vibration is indeed in the Y=0 plane.

CONCLUSION

A new apparatus and processing procedure have been presented, which combined, may prove helpful in providing ground truth for 3-C geophone orientation and polarity. Using three vibrating motors, we can determine the geophone orientation; however, the geophone polarity is still ambiguous. Methods of solving this ambiguity have been proposed, and future work will incorporate some of those ideas to fully solve the polarity determination problem. A short field test using a hand-held 3-C microvibrator indicates that the technique has merit; though the excessive hold-down pressure does not allow the

Z axis vibrate as vigorously as the X and Y axes. Reducing the vibratory force, achieved through a slower rate of rotation, should allow the use of a smaller hold-down force. The author looks forward to continuing testing of this class of apparatus in order to find the optimal system for determining geophone orientation and polarity.

ACKNOWLEDGEMENT

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