Report to the SEG Technical Standards Committee Regarding Polarity Convention for Vibratory Source/Recording Systems

by

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Summary

This report extends the 1975 SEG Technical Standards Committee Recommendations for source/recorder system polarity to include P-wave vibrators which are phase-locked to the estimated ground force (weighted-sum) or reaction mass signals, and to include horizontally polarized (S-wave) vibrators, none of which were prevalent at the time of that first report.

We include a summary of the previous paper's features and conventions that affect vibroseis operations. We define a recommended extension to that convention. We present simple procedures to configure a vibroseis/recorder system to the new integrated convention for both P-wave and S-wave vibrators.

We recognize that any recommended convention is simply a definition that all can use in communication among the various disciplines and operations. For those who wish to setup systems differently, our procedures can be used as a basis of comparison.

A glossary of terms used is included as an appendix.

Introduction

We recommend the following conventions for vibratory source/recorder systems to ensure compatibility and comparability of data in the industry. These conventions are chosen to be, wherever possible, consistent with those published previously by the SEG Technical Standards Committee (Thigpen et al, 1975).

Our objective in establishing a convention is not to prescribe a set of component level standards, but to define a system level polarity. For example, not every company will use the same geophone polarity convention, but these recommendations establish an overall system phase. Similarly, different manufacturer's vibrator controllers internally control the vibrator phasing to different values, but our setup procedure compensates for that.

The 1975 paper recommended a convention establishing the phase relationship between the pilot signal and baseplate motion for a P-wave vibrator. The advent of new methods of vibrator phase control, e.g., using the weighted-sum signal as a phase feedback signal, require additions to the original recommendations. Furthermore, the current use of S-wave vibrators require similar additions. This paper includes these updates.

Moreover, while the original paper recommended using a ruggedized velocity geophone for checking polarity, current use of accelerometers is widespread enough that they should now be included.

Our recommendations will, in theory, produce data whose polarity most closely agrees with P-wave data recorded using the original convention for baseplate motion phase-lock.

We recommend that the reader become familiar with the definitions of terms we use throughout this paper by reading APPENDIX I before continuing.

The 1975 Recommendations

Recommendations affecting Vibratory source/recording systems are paraphrased from the 1975 paper:

> Configure all recording channels, data and auxiliary, to have identical seismic filters.
>
> Polarize monitor camera circuits so that a positive (negative)-increasing sequence of numbers on tape results in a positive (negative)-going kick on a read-after-write record. This holds for all channels including auxiliaries.
>
> Connect spread geophones so that downward impulsive case motion results in a positive kick on a read-after-write monitor record and positive increasing sequence of numbers on tape.
>
> Mount a ruggedized substitute geophone on the baseplate structure and polarize its recording circuit to match the impulsive polarity of the spread geophones. Connect the pilot signal so it leads the signal from that geophone by ninety degrees when the vibrator is locked into phase with baseplate motion.

It was known that companies who had been using different camera and geophone conventions would not want to change them. The foregoing recommendation was simply based on the practice of the majority of users, but it was valid for all.

Updated Convention for P-Wave Vibrators

We recommend a P-wave vibrator polarity (phase) convention that is a simple extension of the previous one:

Configure all recording channels, data and auxiliary, to have identical seismic filters.

Polarize the display system so that a positive (negative)-increasing sequence of numbers on tape results in a positive (negative)-going break[1] on a read-after-write record. This holds for all channels including auxiliaries.

Connect spread geophones to the recorder so that downward impulsive case motion results in a positive break on a read-after-write display system and positive increasing sequence of numbers on tape.

Connect to the recorder an independent vibrator motion sensor(s) located next to the sensor(s) used by the vibrator electronics for phase compensation. Connect the circuit to have the same impulsive polarity as the spread geophones. Use a tape playback of this independent monitor signal as a guide for connecting the pilot signal:

For reaction mass phase-lock, connect the pilot signal so that it is in phase with the monitored reaction mass acceleration signal when the vibrator is phase-locked to a sweep.

For weighted-sum phase-lock, connect the pilot signal so that it is in phase with the monitored weighted-sum signal when the vibrator is phase-locked to a sweep.

For baseplate motion phase-lock, when the vibrator is phase-locked to a sweep, connect the pilot signal so that it:

is in phase with the monitored baseplate acceleration signal, or
leads the monitored baseplate velocity signal by ninety degrees, or
leads the monitored baseplate displacement signal by 180 degrees.

[1] For time increasing to the right, the signal axis is 90 degrees counter-clockwise from the time axis.

Convention for S-Wave Vibrators

Horizontally polarized vibratory sources were not considered in the 1975 paper. Since that time, not only have they found a place in 2-D production profiling, but they have been used experimentally in several aspects of the newer 3-C (three component) and 9-C (3-C, 3-D) experiments.

The extension from a single vertical axis to the 3-C world precludes linking the vibrator and spread geophone polarities together. The solution is rather to define a single three-axis coordinate system to which sources and receivers alike will be referred regardless of their individual orientations.

We have simply followed the recommendations of the SEG Subcommittee on 3-C Orientation in choosing the coordinate system.

We recommend vibrator motion sensors for horizontally polarized vibrators record a positive-going sequence of numbers on tape when their cases are impulsed toward the direction of the POSITIVE axis they represent:

> Z is positive downward.
>
> X is positive in the forward direction of the source vehicle.
>
> Y is positive to the right, ninety degrees clockwise from the forward direction.

For a S-wave vibrator vibrating transverse to the length of the vehicle, a tap on the marked side of either a velocity sensor or an accelerometer along its sensitive axis shall produce a positive first break and a positive sequence of numbers on tape. The accelerometer or velocity sensor shall be mounted on either the baseplate or reaction mass (or both) with the marked side closest to the left side of the vehicle (driver's left).

For a S-wave vibrator vibrating in line with the length of the vehicle, a tap on the marked side of either a velocity sensor or an accelerometer along its sensitive axis shall produce a positive first break and a positive sequence of numbers on tape. The accelerometer or velocity sensor shall be mounted on either the baseplate or reaction mass (or both) with the marked side closest to the rear of the vehicle.

> Configure all recording channels, data and auxiliary, to have identical seismic filters.
>
> Polarize the display system so that a positive (negative)-increasing sequence of numbers on tape results in a positive (negative)-going break on a read-after-write record. This holds for all channels including auxiliaries.

Connect to the recorder an independent vibration motion sensor(s) located next to the sensor(s) used by the vibrator electronics for phase compensation. Connect the circuits so that an impulsive motion of sensor cases in the positive X (Y) direction results in a positive going sequence of numbers on tape for the in-line (transverse) mode. Use a tape playback of this monitor signal as a guide for connecting the pilot signal:

> For reaction mass phase-lock, connect the pilot signal so that it is in phase with the monitored reaction mass acceleration signal when the vibrator is phase-locked to a sweep.
>
> For weighted-sum phase-lock, connect the pilot signal so that it is in phase with the monitored weighted-sum signal when the vibrator is phase-locked to a sweep.
>
> For baseplate motion phase-lock, when the vibrator is phase-locked to a sweep, connect the pilot signal so that it:
>
> > is in phase with the monitored baseplate acceleration signal, or
> > leads the monitored baseplate velocity signal by ninety degrees, or
> > leads the monitored baseplate displacement signal by 180 degrees.

Setup Procedure

Following the polarity recommendations, first ensure that all data and auxiliary channels have identical filters selected. The identical response of the filters should have already been checked by computer analysis through the regular standard instrument test procedures.

Prove the polarity and sequence correspondence of data and auxiliary channel signals on tape and their traces when played back to the field display system. This can be done in a number of ways: by playing back a computer generated tape, or by dumping a tape file and comparing the numbers to a playback are two.

For P-Wave Vibrators

Plug the recording spread into the recorder and tap several groups of geophones on top, recording the taps and making read-after-write monitor records of each. We recommend that these traces break positive.

Replace the spread cables with cables connecting the monitor sensors for the vibrator as outlined in the previous section UPDATED CONVENTION FOR P-WAVE VIBRATORS for the specific method of phase-lock to be used. Tap the unmounted sensors on their tops. Remember that for the weighted-sum phase-lock method, both the baseplate and reaction mass sensors must be tapped. Record the taps and make read-after-write records of them. These tap records must match those of the spread geophones.

When the sensor tap records are satisfactory, mount the sensors vertically as near to the corresponding phase-lock sensors as is possible.

Some of the vibrator electronics models available include a pulse as one of the choices of pilot signals. In all, the leading edge of the pulse will accelerate the reaction mass upwards and the baseplate structure downwards. These pulses can be used to verify the sensor taps you have made, remembering that they correspond to tapping the reaction mass sensor on the bottom and the baseplate sensor on the top.

Cycle the vibrator in the normal recording manner and verify that the system is phase-locked. Record the next cycle, confirming it with a read-after-write paper record. Connect the pilot signal to conform to the convention according to the type of phase-lock used: reaction mass motion, weighted-sum, or baseplate motion. Cycle the vibrator again, making another read-after-write record for verification.

Further verify the phasing by analyzing the crossphase spectrum of the pilot signal or its equivalent and the monitor signal. The polarity convention of 0, 90, -90, 180 degrees refers to the zero frequency intercept of the phase spectrum of the pulse. For crews that have a field correlator we recommend they cross-correlate the monitor signals to confirm the desired phase relationship. This is a useful check that the field correlator polarity is also correct.

CAUTION

Tapping a velocity sensor or accelerometer with a hard object can produce records which are difficult to interpret. It is best to put the sensor on a soft pad or hold it in the hand, and tap it with a soft rubber eraser, or the fleshy part of the finger.

For S-Wave Vibrators

Connect the circuits of the monitor sensors for the vibrators as outlined in the previous section CONVENTION FOR S-WAVE VIBRATORS for the specific method of phase-lock to be used. Tap the sensors on their marked sides. Remember that for the weighted-sum phase-lock method, both the baseplate and reaction mass sensors must be tapped. Record the taps and make read-after-write records of them. These tap records must show positive breaks.

When the tap records are satisfactory, mount the sensors as near to the corresponding phase-lock sensors as is possible.

Cycle the vibrator in the normal recording manner and verify that the system is phase-locked. Record the next cycle, confirming it with a read-after-write paper record. Connect the pilot signal to conform to the convention of phase-lock used: reaction mass motion, weighted-sum, or baseplate motion. Cycle the vibrator again, making another read-after-write record for verification.

Further verify the phasing by analyzing the crossphase spectrum of the pilot signal or its equivalent and the monitor signal. The polarity convention of 0, 90, -90, 180 degrees refers to the zero frequency intercept of the phase spectrum of the pulse. For crews that have a field correlator we recommend they cross-correlate the monitor signals to confirm the desired phase relationship. This is a useful check that the field correlator polarity is also correct.

Recommended Tape Header Code

The original 1975 paper recommended a one-half byte code to be recorded in half byte 22B of the tape header so that anyone processing the tape could discover the polarity of its data.

As a final recommendation, we stress that polarity be recorded in the tape header. This issue is currently being addressed by the tape format subcommittee.

Example Polarity Setup with Illustrations

The following tests were performed following our recommended setup procedure for a P-wave vibrator using the weighted-sum phase-lock technique. Prior to our setup, the crew performed standard startup tests confirming that all recording system filters were alike, all cables and geophone strings were functional, and taps applied to the tops of spread geophones resulting in positive-going breaks on the data traces of monitor records.

i) Display System Polarity

A computer-generated tape having recorded on it two half-scale negative samples for each data and auxiliary channel in sequence was played back to the display device in the recorder. The sequence of negative breaks seen on Figure 1 confirm correct tape to monitor record polarity according to our recommendations.

ii) Vibrator Monitor Sensor Polarities

The spread cables were replaced by a vibrator monitor harness with circuits for the following signals:

A baseplate velocity geophone mounted atop the top cross of the driven structure.

The control loop baseplate accelerometer mounted on the top cross

The control loop reaction-mass accelerometer mounted atop the reaction mass

The weighted sum signal from the vibrator controller

An independent monitor circuit comprising two accelerometers and a summing box. One accelerometer was designated as the baseplate sensor and the second as the reaction-mass sensor. Weighting of the summed signals were set in proportion to the mass of the respective assemblies to form the weighted sum approximation. The sensors were mounted close to those of the control loop sensors.

Figure 2 confirms that the baseplate velocity transducer polarity conforms to our recommended positive break for a tap on top.

Figures 3 and 4 confirm that the independent accelerometer polarities are as we recommend by their positive breaks for downward impulsive case motion.

iii) Vibrator Pulse Test

The monitor accelerometers were placed next to the vibrator phase feedback sensors on the baseplate and reaction mass. The vibrator was pulsed with an initial upward motion of the reaction mass. This produces an initial downward motion of the baseplate. The reaction mass and ground force monitor signals each show an initial negative break (Figure 5). The baseplate monitor signals show an initial positive break.

iv) Vibrator Sweep Test

With the monitor sensors still positioned on the vibrator a 5-65 Hz linear sweep was recorded with the controller set for weighted-sum phase-lock. The uncorrelated weighted-sum signal was seen to be in phase with the auxiliary channel pilot (Figure 6).

Additional Reading

To give some background on these recommendations we have included several references. The original vibrator polarity standard was defined in terms of baseplate motion (Thigpen et al, 1975). Two alternative approaches have been used since that time: reaction mass acceleration (Lerwill, 1981), and ground force (Sallas, 1984). The latter approach was based upon early theoretical work (Miller and Pursey, 1954) and used the weighted-sum approximation of the ground force (Castanet et al, 1965). The polarity convention has been extended to include S-wave vibrators. These recommendations were based on the proposed SEG 3-C sensor conventions. A theoretical treatment of the S-wave vibratory source has also been developed (Cherry, 1962).

REFERENCES

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Lerwill, W.E., 1981, The amplitude and phase response of a seismic vibrator, Geophys. Prosp., 29, 503-528.

Miller, G.F., And Pursey, H., 1954, The field and radiation impedance of mechanical radiators on the free surface of a semi-infinite isotropic solid: Proceedings of the Royal Society, Series A, 223, 521-541.

Sallas, J.J., 1984, Seismic vibrator control and the downgoing P-wave: Geophysics, 49, 732-740.

Thigpen, B.B., Dalby, A.E., and Landrum, R.A., 1975, Special report on polarity standards: Geophysics, 40, 694-699.

APPENDIX 1: GLOSSARY

This glossary is provided to define the terms used in this paper.

BASEPLATE MASS

The value of the total MASS of the baseplate pad, any structure rigidly attached to it, and half the mass of any flexible members (airbags) or linkages (radius rods) attached to it.

GROUND FORCE

The force applied by the vibrator to the earth, usually considered to be the dynamic alternating component of total ground force.

For a P-wave vibrator in operating, but quiescent attitude, the GROUND FORCE is a positive compressive bias created by the HOLDDOWN FORCE. In vibrating mode, the oscillating driven GROUND FORCE alternates about the bias to result in alternately more and less compressive force than the bias.

HOLDDOWN FORCE

The downward force registered by a scale placed beneath the baseplate while the vehicle is jacked up in operation attitude. The direction of this force is considered positive.

INDEPENDENT MONITOR SIGNAL

A separate measurement electrically equivalent to the vibrator phase-lock feedback signal. Used to evaluate vibrator phase performance.

MASS

That characteristic of a body that gives it WEIGHT in the presence of a gravity field.

PILOT SIGNAL

The reference generated in the instrument truck commonly used as the correlation operator.

REACTION MASS

The member of a shaker assembly against which the hydraulic circuit pushes in one direction as it pushes against the baseplate and stilt structure in the other. The value of the MASS of the REACTION MASS includes that of all assemblies rigidly attached to it (e.g. the servo-valve) and half that of all flexible members (e.g. hydraulic hoses) attached to it.

VIBRATOR PHASE-LOCK

The phase of a vibrator output is controlled by feeding back a signal from a sensor(s) attached to its mechanical member(s). The vibrator is driven so that this signal remains in a fixed phase relationship with a reference signal.

WEIGHTED-SUM SIGNAL

The weighted-sum of two accelerometer signals, the first accelerometer being mounted to the reaction mass, and the other being mounted to the baseplate assembly. The positive weightings applied to the accelerometer signals before summing are in proportion to the values of mass of the assemblies to which they are respectively attached.

The WEIGHTED-SUM SIGNAL is useful for approximating the value of the alternating dynamic component of GROUND FORCE. Using the polarity convention for detectors described in this paper, a negative lobe of the weighted-sum signal corresponds to positive downward compressive ground force.

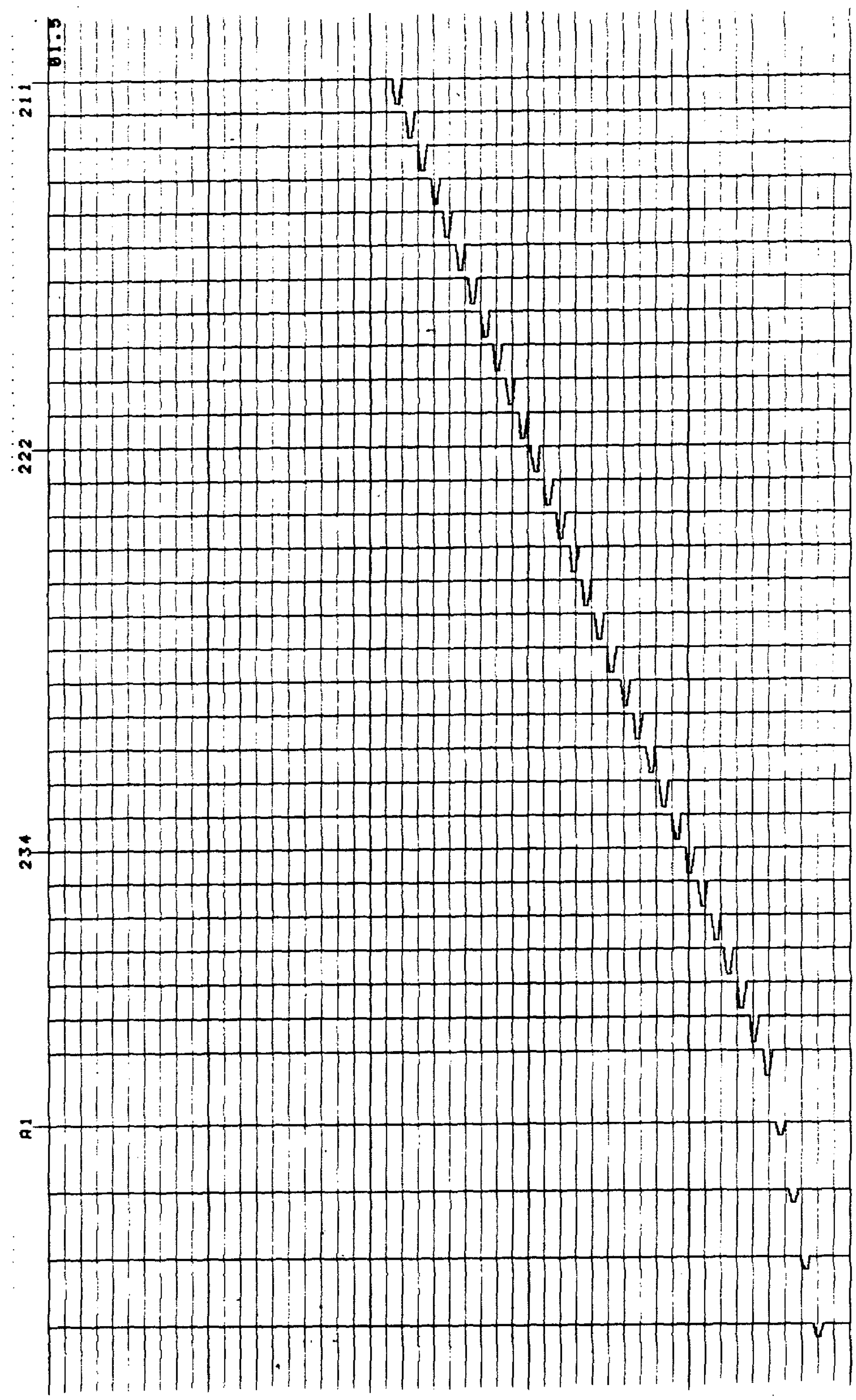

Fig. 1. Playback of a computer-generated tape with two half-full-scale negative samples recorded in sequence through the channel scan verify the recommended polarity correspondence of tape-to-display device.

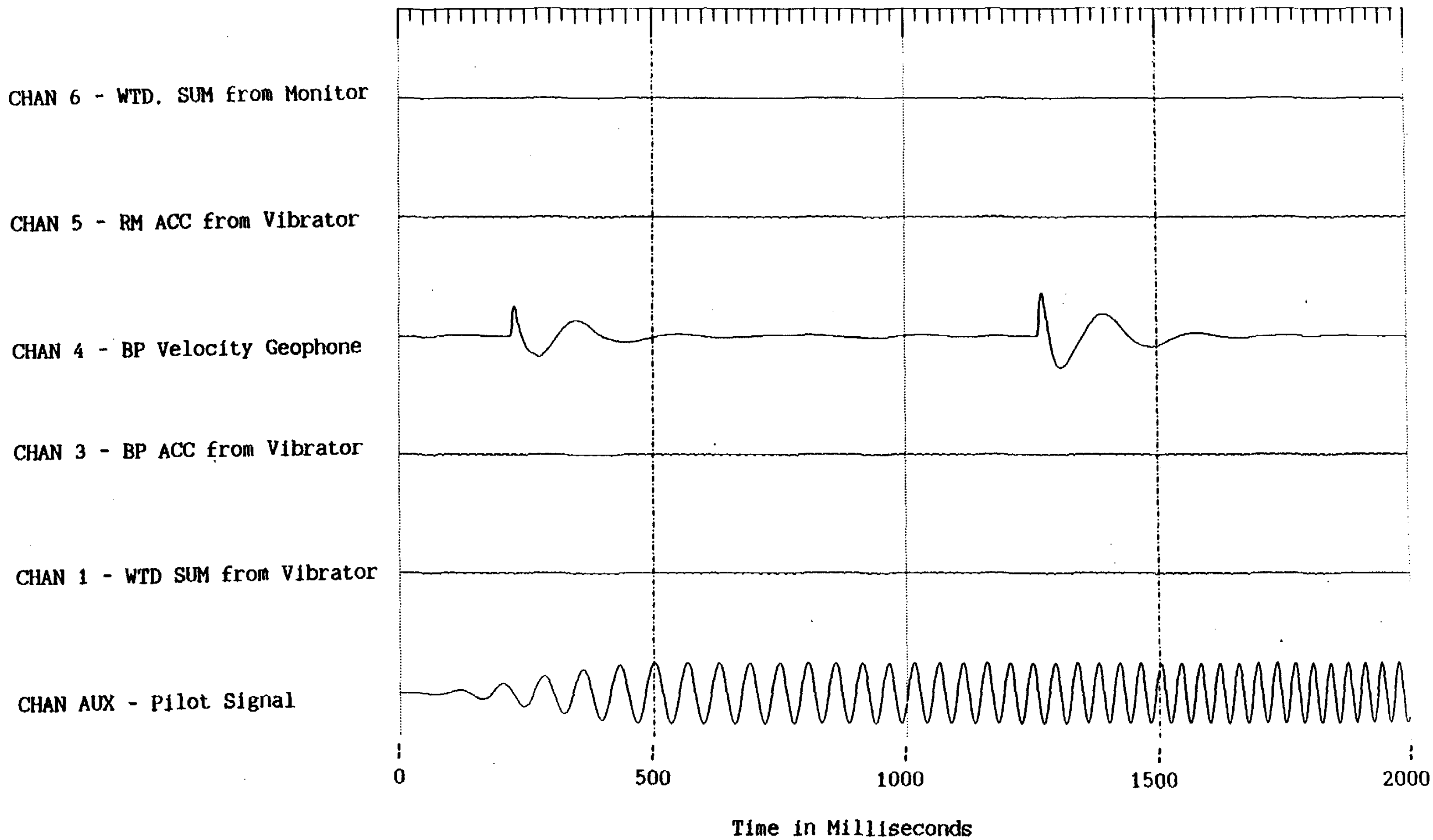

Fig. 2. A tap on the top of an unmounted baseplate velocity transducer connected through the vibrator monitor harness results in a positive-going break on the display device. The detector was subsequently mounted to the top-cross of the vibrator's driven structure.

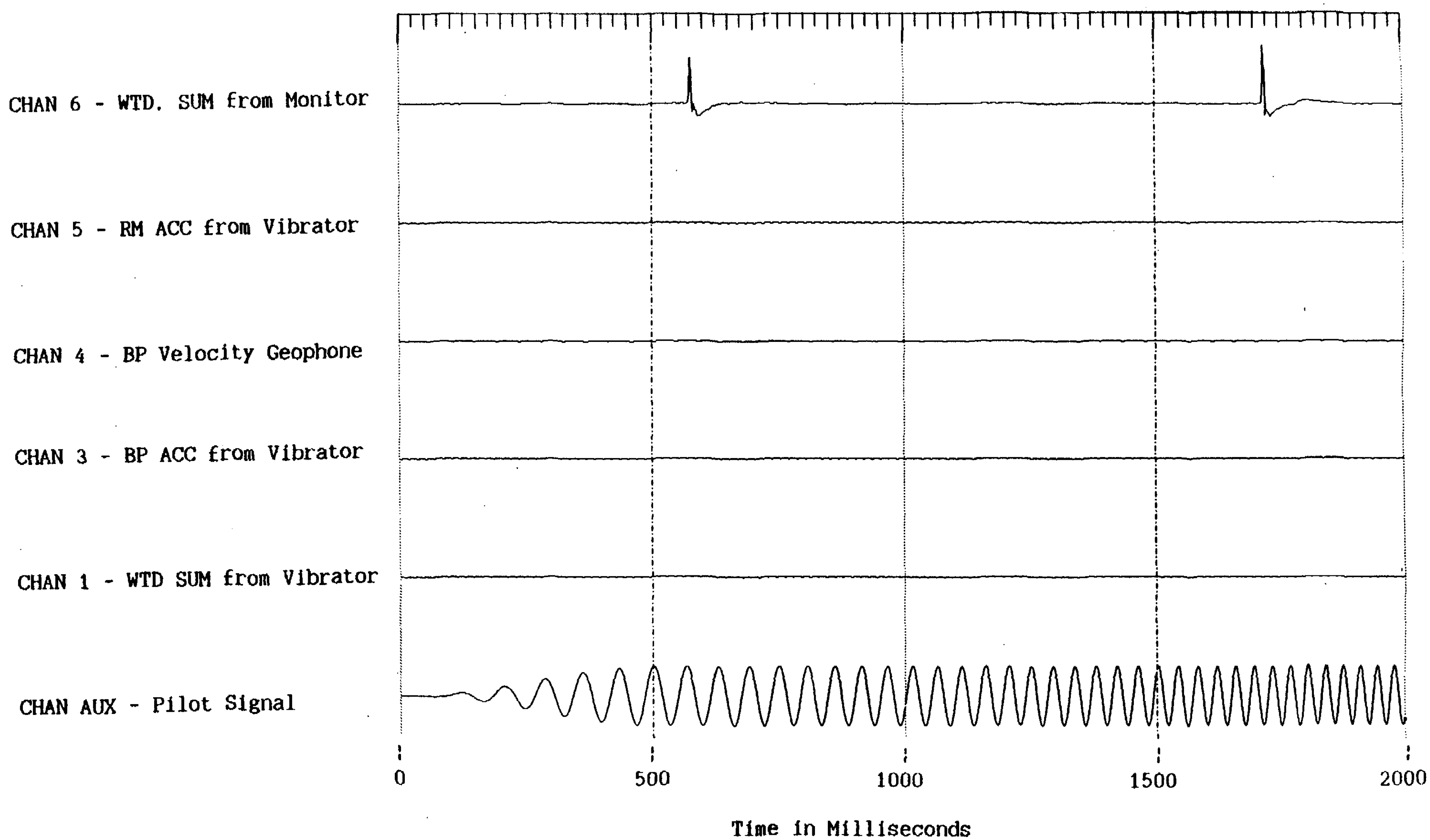

Fig. 3. A tap on the top of an unmounted accelerometer designated as the baseplate accelerometer and connected through the weighted-sum circuit of the vibrator monitor harness results in a positive-going break on the display device. The detector was subsequently mounted to the top-cross of the vibrator's driven structure.

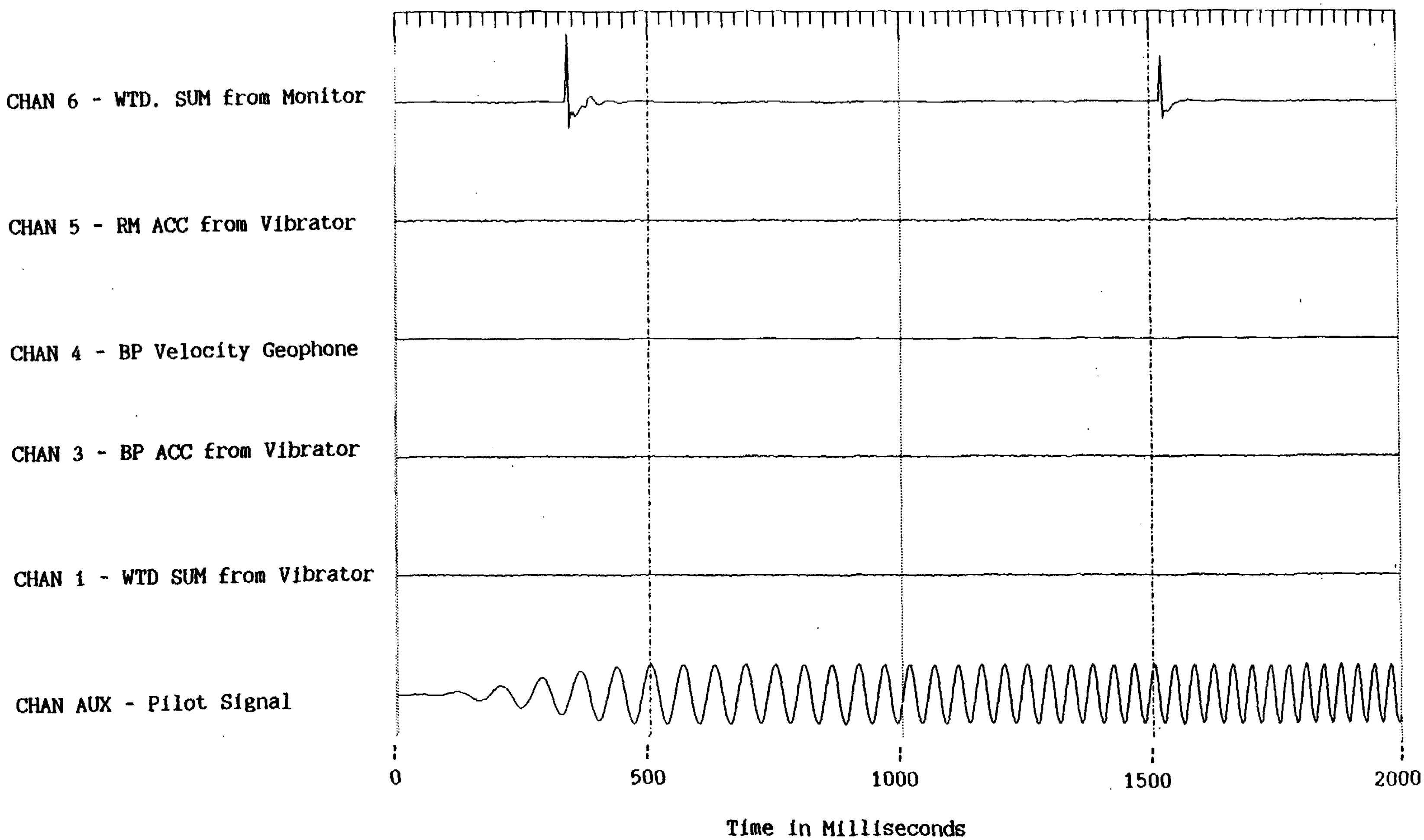

Fig. 4. A tap on the top of an unmounted accelerometer designated as the reaction-mass accelerometer and connected through the weighted-sum circuit of the vibrator monitor harness results in a positive-going break on the display device. The detector was subsequently mounted atop the vibrator's reaction mass.

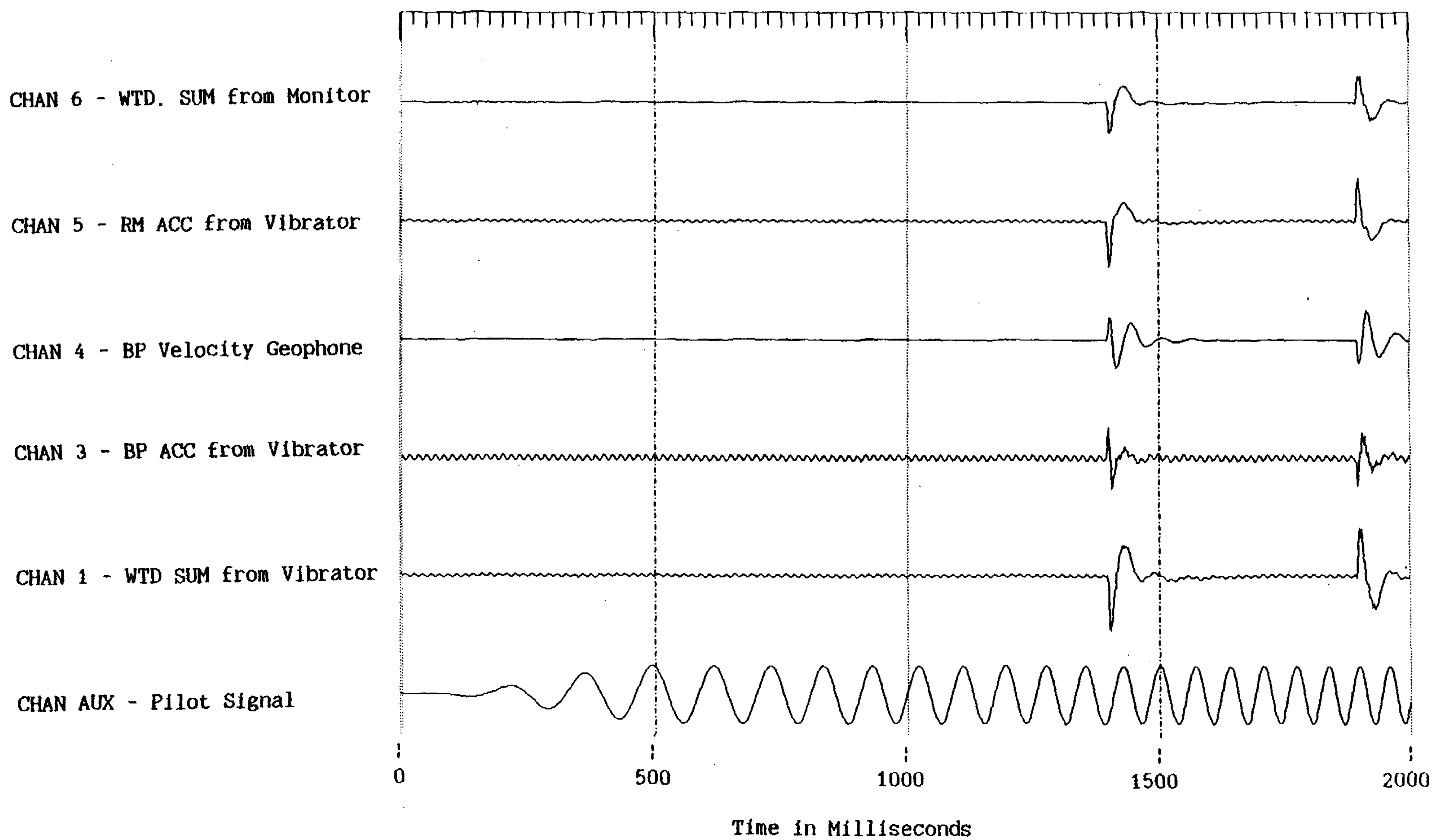

Fig. 5. A step-function pulser which first drives the reaction mass upward and the driven structure downward verifies polarity of the mounted transducers. The first breaks of the reaction-mass and weighted-sum signals are downward, and those of the baseplate signals are upward.

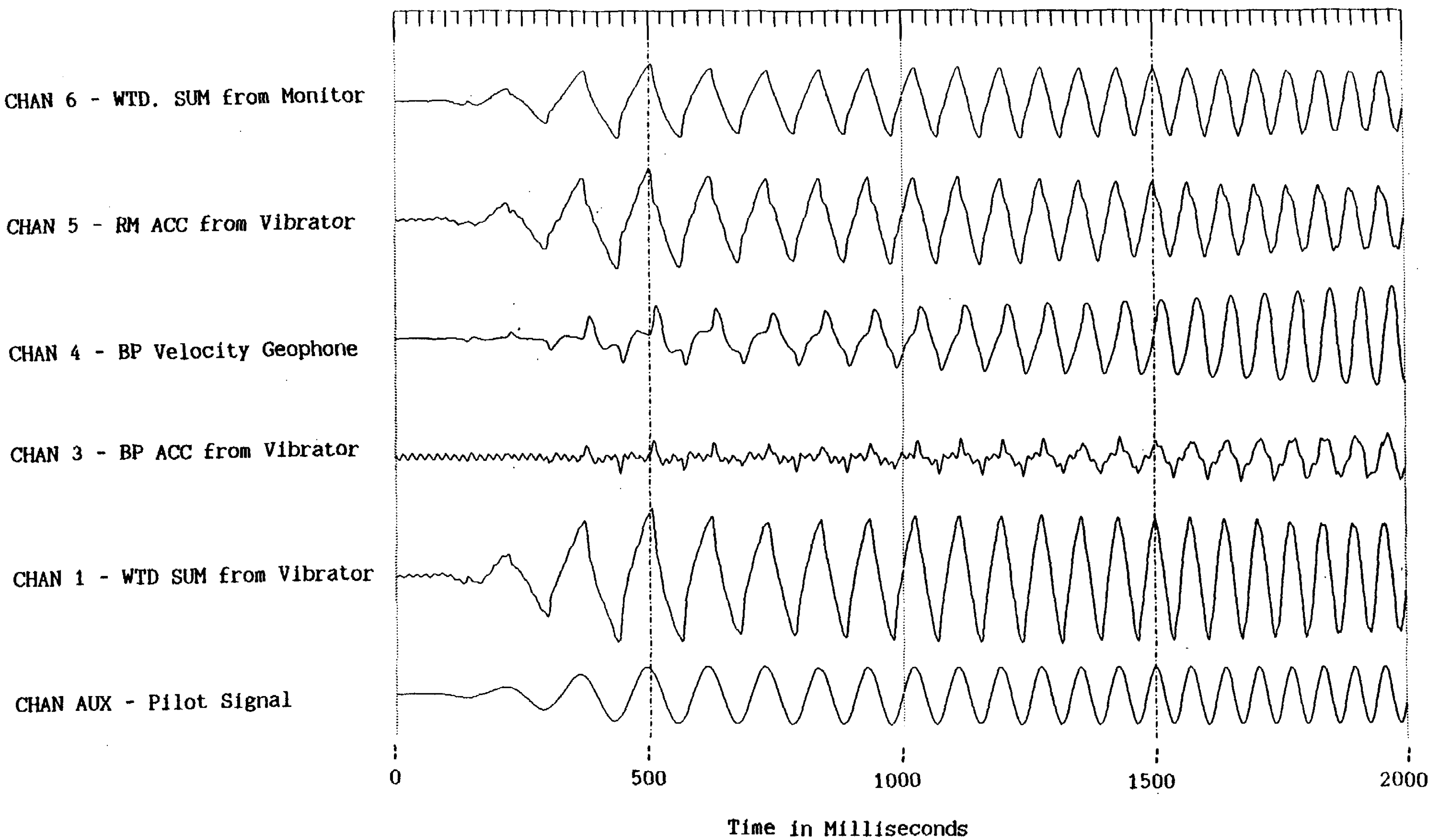

Fig. 6. With the vibrator sweeping and phase locked, the pilot signal polarity is connected to be in phase with the weighted-sum signals. Notice that the velocity signal lags the sweep signal by approximately ninety degrees.