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MASTER

The Problem of Zero Shift

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Zero shift appears as a quasi-static shift in the zero reference level of an accelerometer and results in an output from the accelerometer after the acceleration level has returned to zero. About half the problems attributed to zero shift stem from the electronics used with the accelerometer and not from the accelerometer itself. For example, if the time constant of the input circuit is too short compared with the pulse being measured, the output will be somewhat similar to that caused by zero shift. If one uses a low-pass filter and overdrives the electronics, either the positive or the negative pulse may be amplified more than the pulse of the opposite direction. The amplification error, together with the low-pass filter, may act as a rectifier, and the rectified voltage may look like zero shift. Finally, something like zero shift may be caused by the cables. One can alleviate this problem by using low-noise cables and by tying them down securely. It is not difficult to distinguish between zero shift and either cable noise or too short a time constant in the circuit, but it is frequently hard to tell the difference between zero shift and voltage rectification caused by nonlinear amplification and a low-pass filter. It is, therefore, not advisable to use filters in the circuit unless they are absolutely necessary.

Zero shift becomes a more persistent problem as one goes to higher and higher shock levels. It usually makes its first appearance when an accelerometer is shocked to a g level which is between 100 and 300 percent above the rating of the accelerometer. Zero shift is usually between 10 and 50 percent of the output of the accelerometer, and it may occur either in the same direction as the shock pulse or in the opposite direction. Figure 1 is an illustration of "positive" zero shift. The top line represents the unfiltered output of the accelerometer, and the bottom line represents the same output filtered to eliminate ringing. Figure 2 is an example of "negative" zero shift. The zero shift appears to be much higher than the shock pulse, probably because the filter considerably reduced the indicated peak g level.

Zero shift is, of course, a transient phenomenon. Generally, an accelerometer does not change in calibration after zero shift. The recovery time is fairly consistent with the RC time constant of the input circuit within about 10 percent. Lowering the RC time constant also lowers the time of zero shift. When the sensitivity of an accelerometer does change after zero shift, the accelerometer frequently fails completely within the next few shocks. The change in calibration may be due to some flaw in the crystal itself. Apparently, some accelerometers, before they fail, give an indication which looks much like zero shift. Most accelerometers, however, do not fail after zero shift.

It would be interesting to determine whether the frequency linearity or the amplitude linearity of an accelerometer changes during zero shift, but it is difficult to do any testing on the accelerometer during the few milliseconds between zero shift and recovery. If a crystal is vibrated on a high-g shaker at about the same level where it zero shifts, there seems to be a reduction in its sensitivity. But, of course, no indications of zero shift are present because the pulses are both positive and negative.

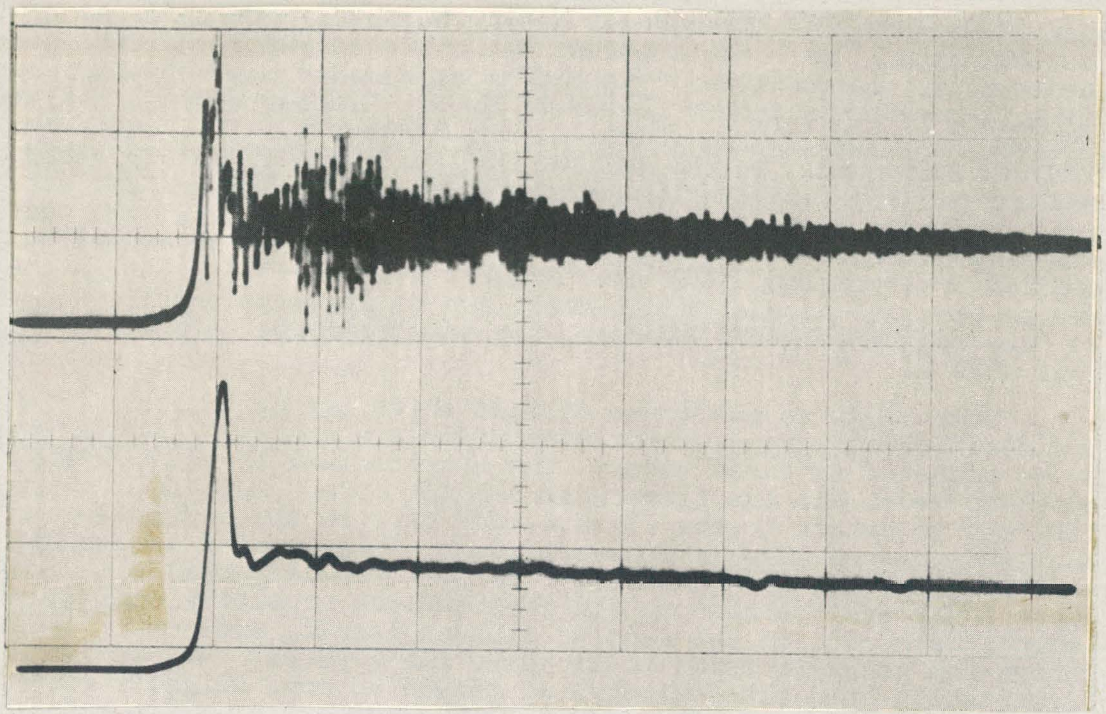

Figure 1 -- "Positive" zero shift.

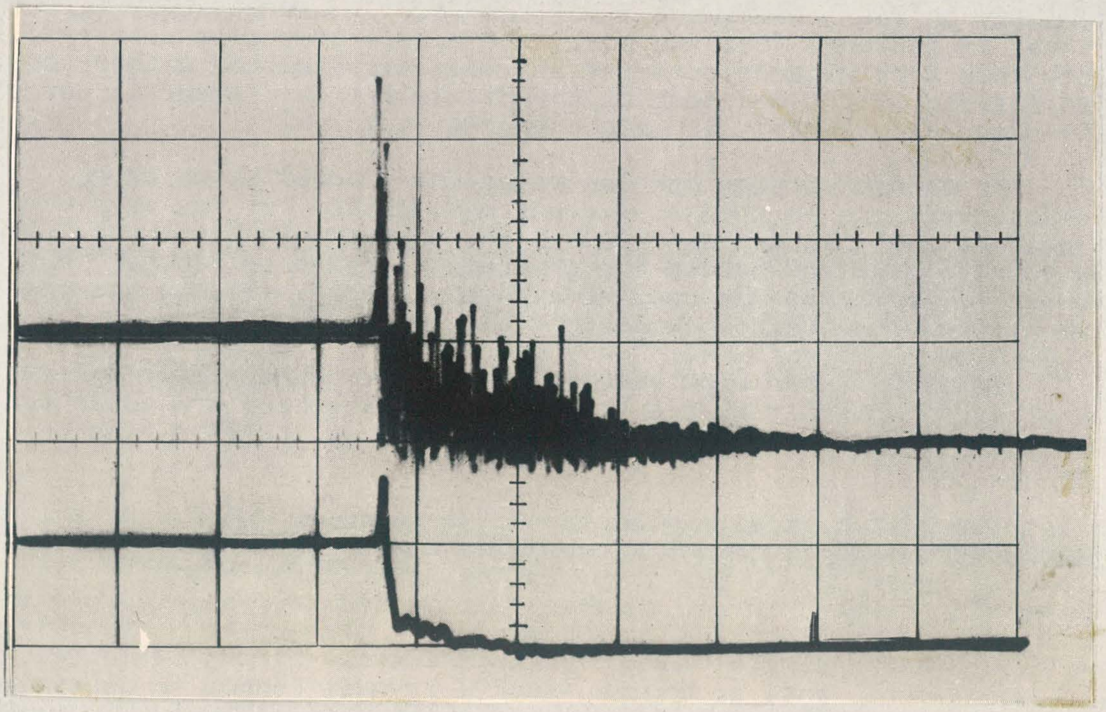

Figure 2 -- "Negative" zero shift.

At present no one has a comprehensive explanation of the cause of zero shift. Transducer design has been considered as a possible cause. One accelerometer may shift at 700 g, while a similar accelerometer manufactured by a different company may not shift below 1200 g. One accelerometer tested by Sandia/Livermore would not zero shift at about 100,000 g, which was the highest g-level Sandia could attain at the time. In the application for which it was intended, however, the accelerometer would see about 15,00 psi, and the accelerometer was quite sensitive to pressure. At 15,000 psi, the output caused by pressure was greater than that which would be caused by the expected acceleration. The manufacturer was asked to redesign the case so that the accelerometer would not be pressure-sensitive. After the case was redesigned, however, the accelerometer zero shifted at about 3000 g.

Some clues to the cause of zero shift may be obtained by a consideration of ways in which accelerometers operate. Accelerometers can be operated in three modes: the longitudinal or extensional mode, the sheer mode, and the flexure or bending mode. Zero shift is most difficult to detect in the flexure mode because the accelerometer is usually destroyed when it it overloaded. This type of accelerometer is no longer being manufactured. The most commonly used accelerometers today are operated in the longitudinal or extensional mode. A weight is placed on the sensing element itself, and during acceleration the pressure tends to elongate the crystal. An early theory of zero shift held that the crystal tended to move slightly with respect to its case and that this slight movement caused a grinding between the microscopic roughness of the crystal and the microscopic roughness of the case. This grinding, it was thought, resulted in an output resembling zero shift. This may be a cause of zero shift, but that it is the only cause of zero shift has been disproved by the introduction of the sheer-type accelerometer. In the sheer-type accelerometer the crystal is bound to a post, and the output is dependent on the sheer force along the face of the crystal. If the crystal is loosened from the post, the accelerometer is destroyed. Since this type of accelerometer has been zero-shifted without destroying it, slight movement of the piezoelectric element is not the only cause--if, indeed, it is a cause--of zero shift.

By careful design one can raise the g level to which an accelerometer can be shocked without zero shift. If the mass used to measure acceleration is reduced, the stresses in the crystal and the voltage gradient across the crystal will also be reduced, and the accelerometer can be used at higher g levels. But at the present time design alone cannot completely eliminate zero shift.

Zero shift has also been attributed to pyroelectric effects, but it seems unlikely that a shock of a few thousand g's could raise the temperature of the sensing element enough to produce a pyroelectric effect.

The most logical explanation of zero shift attributes the phenomenon to high internal stresses in the piezoelectric material. At normal shock levels the atoms in the lattice are slightly displaced with respect to one another, and an electric dipole is formed which creates an electrical gradient across the crystal. Ideally, one should use a single, large, perfect crystal as the piezoelectric sensing element, but, of course, such a crystal cannot be obtained. The local imperfections in the crystal, then, tend to cause local stresses which may result in a reorientation of the electrical domains within the crystal. After the stresses are removed, the electrical domains return to their original alignment. It may very well be that the movement of these electrical domains causes zero shift.

Zero shift is generally not a serious limitation to the use of piezoelectric accelerometers. If one knows the approximate shock levels an application will see, one can generally select a suitable accelerometer, since crystals which will go up to 100,000 g without zero shifting are now available. If one reduces the sensitivity of an accelerometer, however, low levels of acceleration may be lost in noise. If one does not know the shock level and grossly underestimates it, zero shift may occur. But even in this case, the data on the first pulse may be useful. The output from the initial acceleration pulse is usually within 10 percent of that of a standard accelerometer which has not shifted. It appears, therefore, that zero shift generally occurs on the downward side of the first acceleration pulse. If one is interested not in the initial high shock pulse, but in the second pulse--for instance, if one is interested in a deceleration after a rapid acceleration--zero shift would render the data obtained useless.

Dr. Bouche stated that experiments at Endevco indicate that zero shift does not begin until the acceleration levels reach the area where the accelerometer is nonlinear. Therefore, the initial base line and the output from the initial acceleration pulse may provide fairly accurate data.

Mr. Todaro asked what a manufacturer does to prevent zero shift at any given level of acceleration. Dr. Bouche answered that Endevco establishes the linear range of the accelerometer by a combination of sinusoidal and shock motion calibration to ensure that the accelerometer is linear up to the acceleration level at which it is rated. The accelerometer will not zero shift up to this level. If a higher acceleration level is required, the stresses on the crystal for the same applied acceleration are reduced or the material is changed.

Mr. Todaro asked what effect a diagonal shock would have on zero shift. Dr. Bouche answered that the output of the accelerometer would be reduced, but zero shift would still occur if the shock were great enough. For example, if the shock is applied at an angle of 45 degrees, the accelerometer indicates about 70 percent of the acceleration, or a percentage equal to the cosine of 45 degrees.