MEASUREMENT TECHNIQUES FOR HAND-ARM VIBRATION

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ABSTRACT

The author discusses various types of vibration transducers, conditioning systems, and vibration analysis instrumentation. Emphasis is placed on proper use of and expected limitations of each of the above. The author emphasizes that only through proper knowledge of each element comprising a vibration instrumentation and transducer system can a user expect to achieve maximum benefits from this system.

INTRODUCTION

The measurement problems described in some of these presentations are typical of what is going on worldwide—devising ways to test and measure the effects of vibration on humans, vibratory tools, etc. Usually one constructs a test setup by making a measurement with a strain gauge of some kind and then using the deformation of this device caused by acceleration as a vibration measure.

As a manufacturer, that is exactly what we try to do in designing, manufacturing, and testing vibration transducers. After much device testing and data collection, it's possible to correlate what the transducer actually did. Users in research laboratories integrate the transducer into an entire instrumentation system, generally in such a manner that it is not possible to standardize the transducer and obtain repeatable measurements. What I will attempt to do here is informally and briefly discuss some common problems and, in an objective way, perhaps make some helpful comments.

In discussing accelerometers, their frequency range, and the relevance of various frequency ranges, we can say that in hand-arm vibration, we are concerned basically with the 10 Hz to 1,000 Hz range. True enough, some people (mostly those doing whole-body research) are interested in frequencies as low as 0.1 Hz, the area of motion sickness. There are transducers that are well suited for wide ranges, but they are not without problems.

"Piezoresistive" accelerometers are essentially D.C. devices; "piezoelectric" accelerometers are not. As you go from D.C. towards the higher frequencies (i.e., above 100 Hz), you begin having problems with the piezoresistive devices; the mid-range to high frequencies can be improved, but not without compromises. There is a very gray area (i.e., 1 to 10 Hz) where there are problems with both devices. As with any transducer, the problem again concerns setting up some type of deformation in the transducer, whether it is the common strain gauge system, a piezoresistive system, or a piezoelectric system.

In actuality some kind of motion is being transferred into an analogous deformation. In the piezoresistive device, for example, the problem is that these devices normally are torsionally sensitive, and you have to know something about torsional sensitivity before you can conclude what you are doing. Normally, piezoresistive devices have some cross-axis sensitivity; you can rotate them and get an output with no motion in the sensitive direction. For the researcher studying motion-sickness, this could present problems.

VIBRATION TRANSDUCER PROBLEMS

Several papers presented at this conference typify some of the problems that we, as device manufacturers, continually encounter. For example, I recall a user telling us he was destroying every piezoelectric accelerometer he was using while testing air hammers. In particular, he claimed they never exceeded 1,000 g's because there could not be that much acceleration in the handle of an air hammer. And, true enough, only a short time after he received a new transducer, it was ruined. He sent us these devices, and when we disassembled them, the devices were internally ruined. We found by careful measurements on our own that whenever an air hammer idles, there are up to 40,000 g's at the handle! When the workpiece is loaded, the amplitude goes down. In analyzing the vibration spectrum at the handle, very high amplitude spikes occur. The effect is as if the hammer had been dropped on the floor. (This, by the way, is the normal complaint about these transducers; they have been dropped on the floor.) In a normal hand-arm vibration situation, generally we do not exceed 10 g's, and at these accelerations, we do not have a linearity problem with the piezoelectric devices. Many of these devices operating up to 300 to 400 g's will be well within 1% of linearity specification. That means that any measurement below 400 g's would be linear within 1%. But when the 400 g limit is exceeded, depending on the sensitivity, then the accelerometer goes into the nonlinear range and the nonlinearity can become appreciable. When working with the normal hand-arm vibration problem, the linearity error is 0.1% or less. That means that the normal dynamic range available with no distortion is somewhere around 120 dB. This is true for nearly all piezoelectric devices, unless they are very poorly made.

ZERO SHIFT PROBLEM

Another very real problem is that of "zero shift." Normally, a piezoelectric device has a seismic mass in conjunction with a piezoelectric element of some kind. The mass rests in just three points (theoretically, at least), and as soon as a load is put on it, the point of elastic deformation is exceeded. This constant deformation produces a zero shift. (Actually, the mass is resting on new points, which is the same as a zero shift at the output.) Although the deformation is not generally observable if you are using A.C.-coupled instrumentation, it is very observable with direct-coupled instrumentation. Thus, the obligation is on us as manufacturers to reduce the deformation force. This can be accomplished by carefully polishing the inside elements of the unit to reduce deformation, or a mechanical filter can be inserted. If the mechanical filter is used, a piece of rubber is put under the accelerometer element. In doing this, a mass stiffness is introduced; the resonance would be equal to the square root of the ratio of stiffness to mass of the system. The response will depend on the size of the accelerometer.

HAND-ARM PROBLEM

In the hand-arm problem, the question is to decide whether to measure on the hand (which is the real element) or on the tool. If "mobility" measurements are made to determine the transfer impedance from the workpiece to the hand, large mass accelerometers cannot be used. Very lightweight accelerometers are used. If one uses a lightweight workpiece, apply lightweight accelerometers. Using a heavy accelerometer on a lightweight workpiece results in erroneous measurement for only the accelerometer is measured, not the workpiece itself. This is one reason for having a number of different measuring devices.

THE SPIKING PROBLEM AND OVERLOAD PROBLEM

Generally, the "spiking" problem addressed at this conference will normally be in the order of 30 dB. This, of course, is a real problem when the signal output is put into a tape recorder that has only a 40 dB dynamic range. I can see only one way out of this: constantly monitor this spike to make sure that the tape recorder is not overloaded. Place an overload indicator at the output of the transducer. That is the only place it should be. It does not really help to have an overload indicator at higher signal points. One way to do this is by using an oscilloscope or a trigger circuit that is a part of the input amplifier. The overload indicator must be placed ahead of the preamplifier in order to indicate overload before any circuits become nonlinear (i.e., saturated). If you are using weighting networks, filters, etc., you most definitely must make sure that the overload indicator is activated before these circuits are overloaded.

These are some of the important reasons why there are, in my view, some measurement problems—most people are not aware of the fact that they should watch for overloads, especially in situations where there is the possibility of spikes coming from the accelerometer input. A typical input would be, for example, 40 mv on the flat level; but a 30-dB gain times 40 mv equals some 1.2-volt output. So make sure there is at least a 1.2-volt input range available on your final recording system, both in positive- and negative-going directions. That means there must be a peak capability of at least 2.4 volts. I would recommend having an overload indicator or a monitor scope at this point also.

A second type of overload indicator is an earphone. With an earphone, you hear a very typical "cracking" sound in the earphone whenever you have an overload.

ANALYSIS EQUIPMENT PROBLEM

In addressing the analysis equipment, there are problems, especially with integrators. To achieve a velocity output, perform an integration on the acceleration signal. For a displacement output, perform a double integration on the acceleration signal. However, there is a critical point in the integration (depending on the R.C. time constant) that limits low-band capability. Thus, one must be very careful in using integrators.

For spectrum analysis, a real-time analyzer can also be used—digital or analog. In these cases, you can get different answers depending on the selected averaging time. If you are not careful, the measurements will certainly not be correct. In my view, it would be a little easier to use a digital spectrum analyzer. Here, it's important to know that sampling time is artificial. The time period over which the measurement is integrated as well as the crest factor of the input signal (i.e., the ratio of peak to rms signal) is important. Sinusiodal waveforms are no problem, but as soon as there are complex waveforms or single pulse random waveforms, there will be a problem with the analyzing equipment. For pulse sampling, you can easily sample between pulses or just in one place. If you use an analog analysis system, the peak signal, as compared with the baseline, must be handled with care. Just one peak is very difficult to handle.

The ultimate in measurement of hand-arm vibration is a simple, single figure. I am referring, of course, to a so-called "dose meter." There a weighting curve is used; the incoming vibration frequency range is just integrated over time. This is an attempt to get a single figure that will represent some sort of accumulated level. The loss, of course, is in the histogram data.

In this brief presentation, I have tried to highlight what I consider to be typical instrumentation problems, their causes, and possible cures. In conclusion, I should like to emphasize that each user must become and be continually aware of his system's limitation in order to achieve maximum measurement and analysis benefits. I hope you have found this discussion useful.

QUESTIONS, ANSWERS, AND COMMENTARY

Question (D. Wasserman, NIOSH): It is not clear to me what the objection is to using the piezoresistive devices at higher frequencies. You said they are suitable anywhere from 0.1 to 10 Hz. I debate this because we have used them at higher frequencies. Lou Muhic and Doug Reynolds (to name but two) have used them at much higher frequencies.

Answer: I hope I made clear that I have nothing against the piezoresistive devices. First of all they are, normally, single-armed suspended devices. You have a problem of sufficiently coupling the force created by the mass to the element. There are different ways to do that. But the clamping part creates a difficult problem. Normally, a mechanical amplifier gives enough information from the device to transfer motion in a good way into the sensitive element. Some piezoresistive devices cannot be temperature compensated. You cannot get the compensation in the accelerometer. Thus, with such a semi-conductor device, you are forced to temperature compensate the bridge remotely. There are some definite mechanical clamping problems in some of these devices, too. You also have cross-axis sensitivity problems above 100 Hz.

Comment (D. Reynolds, University of Texas): I have used piezoresistive accelerometers in the work I have done in hand-arm vibration. We have checked these fairly thoroughly. We have had a few problems with them; however, it has been *our* fault because of not specifying the right things. We have checked the cross-axis sensitivity, which has been 20 to 30 dB down from the sensitvity of the specified axis. Our accelerometers have had a flat response (and we have measured this) from D.C. all the way up to 1,000 Hz. We measured only about 2 or 3 dB down, up to about 1,500 Hz, and in some cases to 2,000 Hz. In our particular case, we specify our accelerometers from 0 to 1,000 Hz frequency range. When we first ordered these accelerometers, we ordered a very high Q system; in other words, piezoresistive accelerometers with no damping. We failed 11 out of 19 just by dropping them, from a hand, 1 inch onto a table! When the manufacturer replaced them for us, we went to the low Q system or critical damping.

The point that should be made is that there is more than one type of device available to perform a particular measurement.

An additional advantage for the piezoresistive device is the price. With a piezoelectric accelerometer, you buy the accelerometer plus the $700 charge amplifier to use with it. With the piezoresistive device, you pay $270 for the accelerometer. We build our own D.C. amplifiers for about $20 or $30 and get good results. There is a very definite cost factor there.

Answer: You also have to have a bridge D.C. supply, which adds some cost. I have nothing against these devices, and I think they are very good, if they meet your needs.

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