INSTRUMENTATION for PACKAGE PERFORMANCE TESTING

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ABSTRACT

While not required for simple "pass/fail" package performance testing, instrumentation of products and components during test is a powerful approach to achieving the "just right" transport package. This paper will explore the benefits and techniques of using instrumentation to quantify and evaluate package dynamics. Data system components (accelerometers, cables, signal conditioners, and acquisition/analysis computers) will be discussed, plus digital techniques, computations, and signal filtering and fairing.

PASS/FAIL TESTING, INSTRUMENTATION, AND THE "JUST RIGHT TRANSPORT PACKAGE"

Pass/fail package testing as stipulated by ISTA[1] and other organizations generally doesn't require measuring the responses of products and components during test. Certainly the *machine* or *apparatus* must be instrumented in many cases: force must be measured during a compression test, control acceleration must be measured during a random vibration test, velocity must be measured during incline-impact tests, and so on. But instrumenting the *test item* is generally not required – it's simply inspected before the test to ensure proper condition, then inspected after the test to determine if it passed or failed.

A potential problem with this approach is that no hard data is obtained to indicate by *how much* the item passed or failed. It's true that in many cases the nature and extent of damage is visually obvious, and one can differentiate between the marginal and catastrophic situations. But when the potential damage is "hidden" or functional, it's often impossible to tell if the item "almost" passed or failed – or missed the mark by a wide margin. Let's assume we're dealing with a computer, and after the tests it looks OK but won't boot up. Does the package design just need "tweaking", or should we start again completely from scratch? Maybe the product itself has a weakness that needs attention? On the other hand, what if the computer is absolutely fine after the tests? Have we achieved our desired balance of protection, cost, environmental impact, and other factors – or have we grossly over-designed the package?

Suppose we knew, or had a good estimate, of the input levels which would damage the computer and components. We could then instrument our product during the tests, compare measured inputs to known damaging levels, and arrive at the desired "Just-Right Transport

Package"[2] in an efficient and straightforward manner. Even if we don't know anything about product fragility, test data can tell us if our package is working the way we expect. In any case, instrumentation can be used to give additional and important information.

DYNAMIC INSTRUMENTATION FOR PACKAGE TESTING

Instrumentation in its broadest sense is far beyond the scope of this paper. Even coverage of all types of instrumentation commonly used in a package testing laboratory (pressure, force, velocity, etc.) would require considerably more space and time than we have available. But the type of instrumentation which appears to be most complex, and generates the most questions, is *dynamic* instrumentation – specifically accelerometers with their associated cables, electronics, data acquisition systems, and analysis techniques. So this paper is limited to those subjects, but they will be covered in considerable detail.

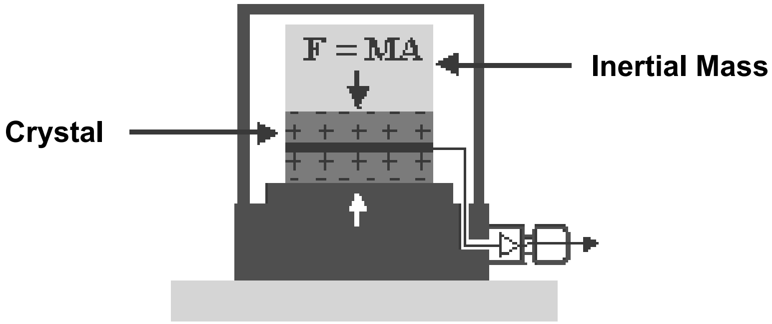
An instrumentation system may considered to have three basic building blocks: sensor, signal conditioning, and readout device. A sensor is a device that detects and responds to input, and can be as simple as a switch that identifies the presence of an object or condition. Accelerometers are a particular kind of sensor called a transducer, defined as a device that converts one form of energy into another. Specifically, typical accelerometers convert acceleration (or deceleration) into electrical energy. To be useful as measuring instruments, the transducer output must have a well-defined relationship to the input (measured) parameter. Accelerometers are usually specified as having a particular and accurate electrical output for each unit of acceleration input.

Signal conditioning in instrumentation systems serves as a link between the sensor and the readout device. It is typically required because the sensor simply cannot connect directly to the readout – it has power or other needs not met by the readout, its output is not directly compatible with the readout input, and so on. Also, functions such as amplification (increasing the signal intensity to make it easier to observe), normalization (adjusting the output to a convenient value), and filtering (removing unwanted signal components) may be required which are not provided by either the sensor or readout. Any or all of these functions can be incorporated in an accelerometer signal conditioner as will be discussed. The conditioner may be a separate electronic component with its own controls or settings, or it may be built into the readout device. In the latter case there can appear to be no signal conditioning in the system, but the functions are there nonetheless.

Readouts are varied based on overall system needs. A simple device may be direct reading, such as an analog (needle-type) or digital meter. Chart recorders make marks on paper using an electrically driven pen or similar mechanism, and can be used with slowly-changing inputs. But since packaging lab acceleration data is dynamic, i.e. rapidly changing, a high-speed readout of some type is required. The current approach is to digitize accelerometer data for input to computer-based data systems. This allows the information to be displayed by the computer, analyzed, manipulated, documented, and stored.

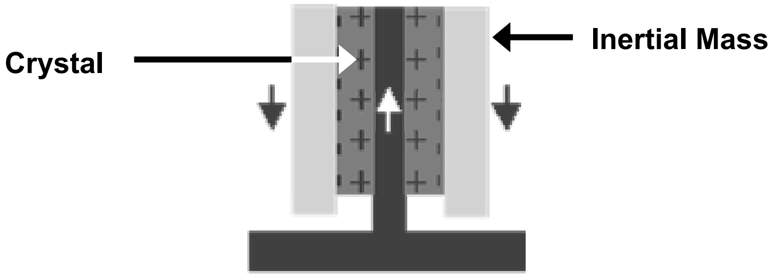
Accelerometers[4]

Piezoelectric Accelerometers. Certain crystals (quartz, tourmaline, special synthetics, etc.) exhibit what is called the "piezoelectric effect". When a force is applied to the crystal causing it to compress, stretch, bend, or otherwise deform, an electrical charge collects on the surface of the crystal. Many types of transducers can be based on the piezoelectric effect, and in the package testing laboratory this is the most common transduction principle for our shock and vibration accelerometers. In a piezoelectric accelerometer, a small weight (called an inertial mass) acts on the crystal when the body of the transducer is subjected to acceleration or deceleration. Newton's Second Law of Motion tells us that the force produced by the inertial mass is equal to its mass times the applied acceleration (F=MA). This force causes the crystal to deform, which in turn produces a charge proportional to the applied acceleration. A simplified drawing of a piezoelectric accelerometer is shown below.



Piezoelectric Accelerometer (Compression Mode)

The configuration of the accelerometer shown above is called "compression mode", meaning that the crystal is put into compression (and tension) by the action of the inertial mass, thus producing the charge output. This was once a common design, but almost all piezoelectric accelerometers sold today use a "shear mode" configuration, where multiple crystals are distorted in shear (movement in a direction parallel to the plane of contact) by the mass. This is shown below.



Piezoelectric Accelerometer (Shear Mode)

Here the crystals are attached to a vertical post (there are often three crystals, mounted 120° apart around the post), and the inertial masses may be retained by a ring which surrounds and grips them tightly. When acceleration is applied along the axis of the post, the crystals are distorted in shear and a charge is produced.

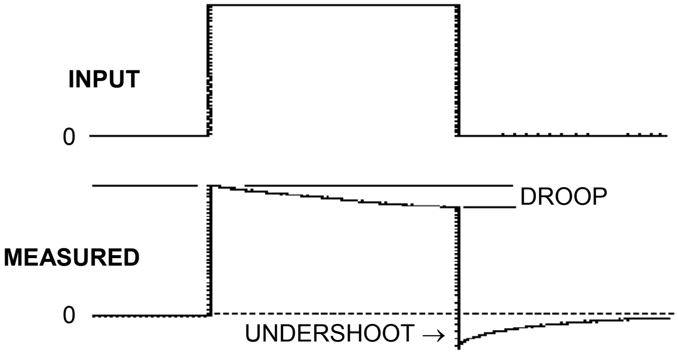
Shear mode accelerometers have proven themselves to be superior to other types (and particularly compression mode designs) in terms of:

- Temperature effects. Piezoelectric crystals respond somewhat to temperature. In the compression design, if the accelerometer base gets hot or cold, that change is quickly transmitted to the crystal. The post of the shear mode configuration tends to isolate the crystals from temperature change.
- Extraneous forces. If an accelerometer is tightly mounted to a surface (as it should be for proper measurement) and the surface bends, stretches, or otherwise distorts, the base of the accelerometer will likewise tend to bend, stretch, or distort. In the compression mode design, base distortions directly act on the crystal, causing errors. The post of the shear configuration tends to isolate the crystals from base distortion.
- Cross-axis motion. Piezoelectric accelerometers are designed to be single-axis devices (vertical motion, in the figures above). Accelerations in the cross axes result in small signals which are considered to be noise or errors, not data. In the compression design, side-to-side motion creates shear on the crystal, and although design techniques are used to control it, there can nonetheless be significant error outputs. With shear mode, the crystals tend to compensate one another – when one is in compression the other is in tension, and so on. The result is lower cross-axis sensitivity and smaller errors.

Triaxial Accelerometers. As stated, piezoelectric accelerometers are uniaxial devices. There are three-axis units, called *triaxial accelerometers*, but these are really three separate transducers with three separate outputs, all mounted in a single housing.

No DC Response. Under static conditions, the charge produced by piezoelectric accelerometers “leaks away” with time. That is, with a constant force applied to the crystal, the charge will not remain constant but will decay to zero. Piezoelectric accelerometers must have a *change* in acceleration to produce an output, and have a low-frequency limit of – not zero Hertz – but typically in the 1-5 Hertz range. Zero Hertz is often called DC, for “direct current”, meaning that the frequency of change is zero. So it is often stated that piezoelectric accelerometers “do not have DC response”. [It should be noted that accelerometers can be made using other transduction principles (strain-gage, capacitive, etc.) which *do* have DC response, but these are not often used in packaging laboratories because we are typically dealing with *dynamic* events where DC response is not needed. And piezoelectric accelerometers have other attributes, such as ruggedness, small size, etc. which usually make them preferable for our purposes.]

If a quasi-static acceleration (such as a very long time-duration shock pulse or a very low-frequency vibration) is applied to a piezoelectric accelerometer, it may not measure accurately – depending upon the relationship between its low-frequency response and the input signal frequency. In the packaging laboratory, this can become an issue when measuring the square wave shocks produced by a horizontal impact test system. In the figure below, the top portion represents the actual acceleration, a long-duration square wave pulse. The bottom portion represents an accelerometer's corresponding output – it "droops" during the pulse, and "undershoots" after the pulse. As can be seen, there is still a measurement but it is not a faithful and accurate reproduction of the input.



Effect of "No DC Response" on the Measurement of a Long-Duration Shock Pulse

A good general guide for limiting these errors to reasonable values is to select an accelerometer which has a low-frequency response satisfying the following recommendation:

$F_{LC} \leq 100 \div$ Pulse Duration

Where **F_{LC}** is the accelerometer's "low-frequency limit" from its specifications
Pulse Duration is measured in milliseconds.

Example: for a 300 millisecond pulse, the accelerometer's recommended low-frequency limit should be 0.33 Hz. or less.

If the accelerometer's low-frequency performance is specified in terms of "discharge time constant", then the recommendation is:

$TC \geq .02 \times$ Pulse Duration

Where **TC** is the accelerometer's "discharge time constant" from its specs
Pulse Duration is measured in milliseconds.

Example: for a 300 millisecond pulse, the accelerometer's recommended discharge time constant should be 6 seconds or greater.

If a pulse measurement or phenomenon like the above is observed, and it is known that the errors are due to poor low-frequency accelerometer response, the data can be at least somewhat compensated. Since the undershoot *after* the pulse is indicative of the droop *during* the pulse, the amount of droop can be "pro-rated" with time and added onto the measured signal

– i.e., add ¼ of the amount of droop to the signal value ¼ of the way through the pulse, ½ the amount of droop to the midpoint of the pulse, etc. While not completely correct theoretically, this can improve the data accuracy to some extent.

High-Frequency Response. Since piezoelectric accelerometers use a mass which acts on a crystal that deflects slightly under load, an accelerometer behaves much like a simple spring-mass system. Like all spring-mass systems, accelerometers thus have a frequency where they over-respond to input, or resonate. At or near resonance, the output is no longer directly proportional to acceleration, so resonance creates an *upper-frequency* limit of usability. For piezoelectric accelerometers, this is usually well beyond the packaging-lab frequency requirements, but may become an issue for measuring very short shock pulses or very high-frequency vibrations.

Charge- and Voltage-Mode Accelerometers. Within the general category of piezoelectric accelerometers, there are actually two sub-types commonly used in the package testing laboratory. One type has *only* the crystal-and-mass arrangement described above, while the other has some electronic circuitry (usually called a “charge converter”) built-in. The external cabling and signal conditioning requirements for these two types of accelerometers turn out to be quite different, as will be discussed in following sections.

The accelerometer type with just the simple crystal-and-mass configuration is said to have a “charge output”, meaning that the output signal is in the form of an electrical charge. There is no industry-standard name for this type of accelerometer, but various manufacturers call them “charge”, “piezoelectric”, or “high-impedance”. Charge is a rather delicate quantity, which accounts for the special cable and signal conditioning requirements that will be discussed later.

The accelerometer type with a built-in charge converter puts out a voltage signal. These accelerometers are variously called “voltage”, or “low-impedance”, or by the trade names “Piezotron”, “ICP” (integrated-circuit piezoelectric), “LIVM” (low-impedance voltage-mode), or “Isotron”. Since voltage is a more easily-handled quantity, signal conditioners and cables for voltage-mode accelerometers can be relatively simple (and inexpensive).

Practical Aspects of Accelerometer Selection and Use

Selection of Accelerometers. When selecting an accelerometer, specifications should be carefully checked against the particular measurement requirements. Depending upon the situation, any and all of the unit’s characteristics may be important. The most basic considerations include the following: The *range* must be appropriate for the amount of acceleration to be measured. If the range is too high (example – a 1000 G accelerometer measuring 0.5 G of vibration), accuracy may be compromised. If the range is too low, the measurement won’t be taken at all and the accelerometer may be damaged. The *frequency response* must be adequate. This is generally not a problem in the package testing laboratory, with the possible exception of measuring long-duration horizontal impacts as was discussed above. The *weight* must be low enough to have minimal effect on the measurement to be made. If the mass is too great in relation to the mass of the component or structure which is accelerating, inaccurate readings can result. A good guide is to limit the accelerometer's weight to 1/10th or less the weight of the structure being measured. Finally, the accelerometer's *size* and *configuration* (including type of mount and cable access) must fit the space available.

Accelerometer Mounting. The method of accelerometer mounting can have a significant effect on quality of the data. Any material superimposed between the accelerometer and its mounting surface, or any looseness or loss of contact can cause false, spurious or inaccurate readings. The best and most reliable method is a threaded fastening mounted directly to a smooth, flat surface. Often this is not possible or convenient, however, and methods using various adhesives, cements, magnetic mounts, tapes, and waxes can be used with good success depending on the situation. The order of preference is usually threaded, then strong adhesive (like epoxy), cyanoacrylate adhesive ("super glue"), hot-melt adhesive, (be careful that the temperature limit of the accelerometer is not exceeded), magnetic mount, wax (beeswax or petro wax), and lastly tape. Of course, considerations of damage to the mounting surface and/or to the accelerometer in given situations may preclude some of these mounting methods.

The accelerometer should be mounted so that its sensitive axis is aligned as accurately as possible with the acceleration direction to be measured. Any misalignment will result in an error which is proportional to the cosine of the angle between the accelerometer's measuring direction and the direction of actual motion. [Example – If an accelerometer is mounted at an angle of 10° from the direction of actual motion, it will measure only a component of the acceleration A, equal to A x cosine 10° = A x 0.985, which is an error of 1.5 %.]

ASTM Standard Practice D6537[3] contains some excellent information on accelerometer mounting, and on usage and data analysis in general.

Initial Connection, Accuracy. Because of the nature of piezoelectric accelerometers, both charge and voltage types, they are not ready for measurement immediately upon being connected to their cables and signal conditioners. Anywhere from a few seconds to nearly a minute may be required for the output signal to stabilize such that reliable measurements can be taken. Further, it should be noted that piezoelectric accelerometers are not exceptionally high in accuracy. Most test methods require acceleration accuracies to within only 5% of true value, and even this may be somewhat optimistic.

Accelerometer Cables

Piezoelectric accelerometers are typically connected with small diameter, flexible cables. This is to avoid mass loading on the accelerometer and structure being measured. Voltage-mode accelerometers can use rather ordinary (except for small size and flexibility) coaxial cables, but charge-mode types require special “low noise” cables. A low noise cable employs special materials and manufacturing methods to accommodate the delicate nature of electrical charge, and also to minimize “triboelectric effect” – a tendency for the cable itself to generate charge (if the cable generates a charge, it can’t be distinguished from the charge produced by the accelerometer, and a direct error results). This leads to a recommendation to always tape or otherwise secure accelerometer cables to prevent “whipping” action during movement.

An important point to be remembered is that cables for the two accelerometer types are *not* interchangeable. While it’s permissible to use a low noise cable on a voltage-mode accelerometer (although unnecessarily expensive), one must *not* use a voltage-mode cable (or ordinary coax) on a charge-mode accelerometer. Unacceptable measurement errors would result.

Accelerometer Signal Conditioners[4]

There are two basic types of piezoelectric accelerometer signal conditioners, corresponding to the two sub-types of accelerometers. Special electronic instruments called charge amplifiers are required for use with charge-mode accelerometers. These have an extremely high input impedance (often 10^{14} ohms or more), and may use sophisticated charge-balancing techniques to measure the input charge without degrading it. Charge amplifiers are relatively expensive, and in addition often have extra built-in features such as amplification, normalization, filtering, computer interfaces time-constant setting, etc.

On the other hand, signal conditioners for voltage-mode accelerometers can be relatively simple and inexpensive. Since charge conversion is done inside the accelerometer itself, the main function of the conditioner is to supply power to the charge-converter circuits. This is usually provided in the form of a constant current of a few milliamps. In a unique arrangement, the acceleration signal is fed back through the same wires that supply power. The signal must be separated, or “de-coupled” from the power flow at the conditioner, but this can be accomplished with nothing more than a capacitor. These signal conditioners are often called “power supply/-couplers”.   They are available in various configurations, from small battery-powered units intended for portable use, to instruments with all the features described for charge amps above.

A third type of accelerometer signal conditioner is really a combination of the first two. Typically called a “dual-mode charge amplifier”, it can perform both charge amp and coupler functions – but not at the same time, and not automatically. It must be switched between the two modes, and often has different input connectors for the two different accelerometer and cable types. This is the most expensive kind of conditioner for the purpose, but also the most versatile.

Obviously a dual-mode charge amplifier can work with either accelerometer type, but the basic two signal conditioners are *not* interchangeable. In other words, a charge amp *cannot* work with a voltage-mode accelerometer, and a coupler *cannot* work with a charge mode accel. It usually doesn’t cause damage to plug incompatible devices together, but is not recommended and can’t be made to work properly regardless.

Signal Filtering and Fairing

A coffee filter separates the grounds from the coffee. In a similar way, a signal filter separates unwanted frequency components from acceleration data. Filtering is commonly performed electronically by the signal conditioner, with software by the data system computer, or both. But regardless of how and where it is accomplished, filtering is a subject which seems to generate a good deal of misunderstanding. Hopefully this section will help to dispel some of that confusion.

In the general sense, "filtering" is defined as the passage or rejection of certain frequency components of a signal. The most common type of package test filtering removes high-frequency portions of the signals from accelerometers used in shock or vibration measurement. Such a filter is called a "low-pass" filter – it "passes" low frequencies but removes high ones. There are other filter types (high-pass, band-pass, and band-reject) but we will confine this discussion to low-pass filters because of their widespread use in our applications.

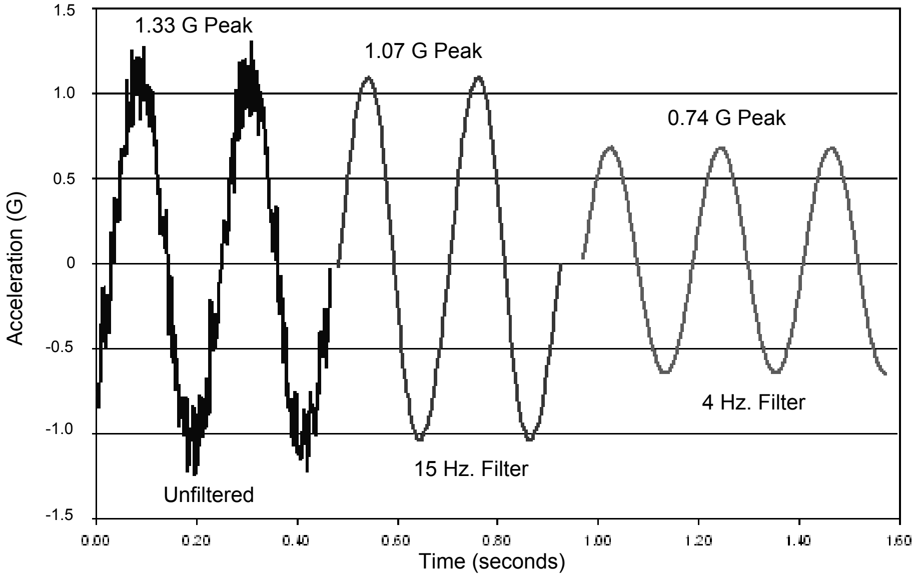
Why do we need to filter, why do we need to reject high-frequency components of our data? Because, in many cases, high-frequency components are "noise" which obscures or degrades the data that we want to measure. If we want to hear our car radio better, we roll up the window; if we want to measure acceleration better, we use a low-pass filter.

Improper filtering, however, can degrade or destroy the accuracy of the data. Like many tools, it is very helpful when properly used but can be harmful if misused. This is the problem, and the source of misunderstanding – what filtering is "proper", and what filtering is "improper"?

The figure below shows a 4.55 Hz. sine wave with superimposed higher frequency vibrations – first unfiltered, then filtered at 15 Hz., then filtered at 4 Hz. This data was taken from the table of a fixed-displacement vibration tester performing in accordance with ISTA Procedures (it should be noted that accelerometer instrumentation of the table is not required for these tests, this data was taken as an illustration).[5]

Vibration Measurement and Filtering

4.55Hz. Fixed-Displacement Vibration



The higher-frequency vibration is probably due to bearing chatter, drive chain action, structural ringing, and other factors. If the objective is to get the best possible measurement of the 4.55 Hz. sine wave, then this “noise” (undesirable signal) makes the principal vibration difficult to accurately interpret (the peak acceleration appears to be 1.33 G, and would be read as such by a data system). The 15 Hz. filter “cleans up” the signal and makes its measurement more precise (with a peak reading of 1.07 G), but without changing the principal waveform. This is an example of “proper” filtering to meet the objective.

The 4 Hz. filter has cleaned up the signal, but also reduced the apparent intensity of the vibration (to 0.74 G peak), and the data system would report that the vibration level was lower than its actual value. This is an example of “improper” filtering with respect to the objective.

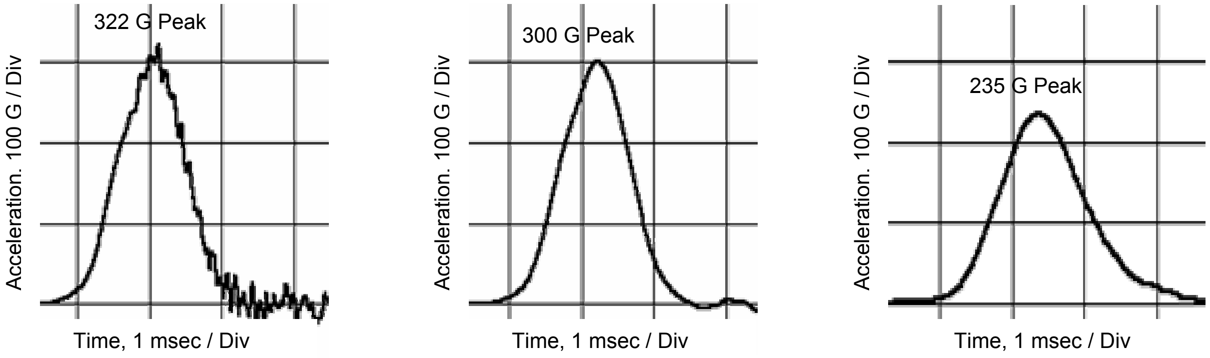
The difference between “proper” and “improper” is apparent in this case. The objective was to “pass” the 4.55 Hz. component: clearly a 15 Hz. low-pass filter will do that, and just as clearly a 4 Hz. low-pass filter will not.

Below is a similar example, but using shock rather than vibration data. The pulse on the left is unfiltered, the same pulse is then shown “properly” filtered (middle), while on the right it is shown “improperly” filtered. The principle pulse frequency is approximately 275 Hz., and the filter frequencies are none, 1500 Hz., and 350 Hz. respectively. [Principle pulse frequency is calculated by measuring the pulse effective time duration in milliseconds, multiplying by 2, and dividing the answer into 1000; i.e.

$$\mathbf{F_P = 1000 \div (T_P \times 2)}$$

Where **F_P** is the pulse frequency in Hz.

T_P is the effective pulse duration in milliseconds]

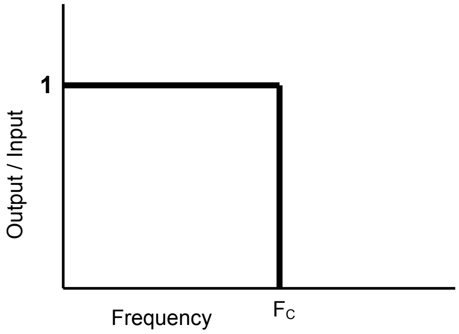


Shock Measurement and Filtering

Here the 1500 Hz. low-pass filter is “proper” because its frequency is higher than the pulse frequency. But why is the 350 Hz. filter “improper”? Its frequency, although close to the principle pulse frequency, is still higher, so why does it distort the data? The answer lies in an understanding of how real low-pass filters work.

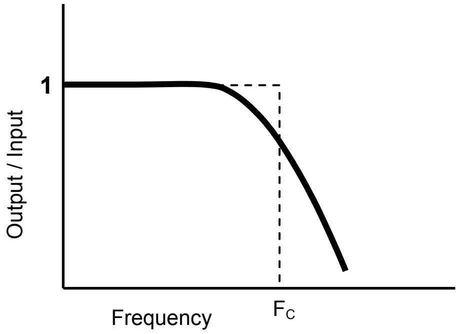
An *ideal* low-pass filter would perfectly pass, without any distortion or degradation, signal components exactly up to its specified frequency (called the "cutoff" frequency, F_C), then completely reject all components above F_C. Its Output/Input ratio, plotted vs. frequency, would look like the figure below.

Ideal Filter Characteristic



Unfortunately, real low-pass filters do not have such a "brick wall" cutoff characteristic. Real filters have a rather smooth transition between their "pass" and "reject" areas as shown in the following figure (the ideal characteristic is shown dotted for comparison).

Real Filter Characteristic



By standard electrical engineering convention, the cutoff frequency of a filter is defined as the point at which the output signal is 70% of the input. For our purposes, that's an unacceptable amount of distortion and error (30%!). So we can't set a filter's cutoff frequency to be at or just slightly above our highest frequency of interest, we must make it considerably higher. Taking into account "typical" filter characteristics, a common and effective approach is to set the filter frequency to approximately 5-times (or more) the principle frequency or frequency of interest, thereby placing the principle frequency on the "flat" portion of the filter characteristic. That explains the selection of 15 Hz. for the vibration example above, and 1500 Hz. for the shock example. It also explains why the 350 Hz. filter distorts the shock data – the principle frequency is on the filter's "rolloff" portion (the transition from "pass" to "reject").

It can be seen that if the principle frequency and the "noise" frequencies are too close together, a typical real low-pass filter cannot adequately separate them. More on that later.

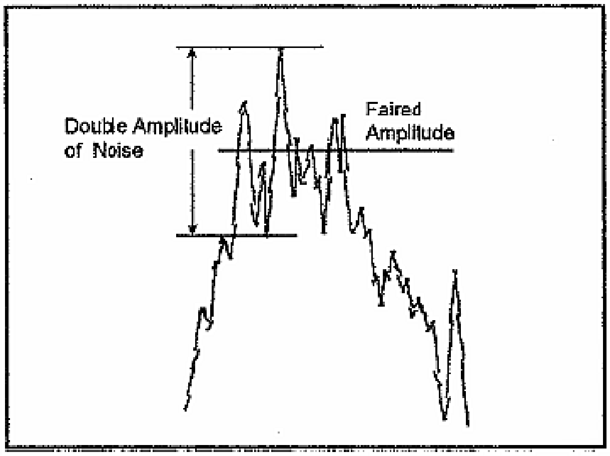
Sometimes the filter frequency is specified as the "down 5% point". That means not a 30% error, but only a 5% error at the filter's frequency. Obviously a filter identified in this way can be adjusted with its frequency much closer to the signal component frequency of interest.

Different filter designs and configurations also have different shapes to their “rolloff” area. Some are rather smooth, like in the figure above, some have a sharper corner and a steeper rolloff slope (although never achieving the *ideal* characteristic). This means that the same signal, filtered at the same frequency but with filters having different characteristics, can appear to be different. It is very important, when making data comparisons or testing to satisfy performance specifications, that all filter parameters be clearly understood.

In the vibration example above, the objective was to accurately measure the 4.55 Hz. vibration. But if the objective had been to study the bearing chatter, drive chain action, structural ringing, etc., then the 15 Hz. filter would *not* have been proper. Similarly in the shock example, if the objective had been to study the “noise” instead of the principle pulse, the 1500 Hz. filter would *not* have been proper. So “proper” must be defined in terms of the *frequency or frequencies of interest*. When dealing with a measurement situation that is new, or where one doesn’t know what to expect, the safest approach is to take *unfiltered* data, examine it to determine (at least roughly) the highest frequency of interest, then (if necessary) filter at a frequency of about 5-times that value as a start.

Fairing. As mentioned above, if the “noise” frequency is too close to the frequency of interest, a typical real low-pass filter cannot adequately separate them. Because of the filter’s rolloff characteristic, the noise is not adequately rejected or the desired signal is being distorted, or both. This is when a technique called “fairing” can be useful. Fairing is defined as a graphical smoothing of the data by drawing a line or establishing a point midway between the positive and negative peaks of the unwanted high frequency signal, in a particular signal area. This is illustrated in the figure below (taken from ASTM D6537[3]).

Signal Fairing

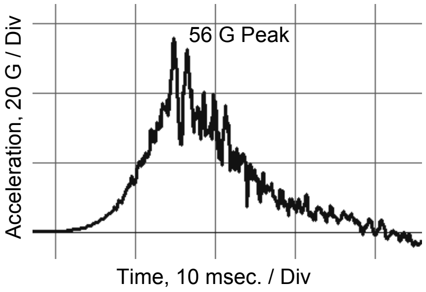


Fairing is typically a manual operation, not done electronically or automatically. But most data systems will allow the user to move a cursor or pointer along the signal, and override data values. So (typically by estimation) accuracy can be improved by establishing a user-specified faired peak amplitude to replace a false peak caused by noise, even when low-pass filtering is unable to completely remove the noise.

Proper Filtering (and Fairing) is Important! The following is a real-world example of the technical – and *financial* – importance of proper filtering. It is not a particular specific case, but an imaginary composite of situations the author has encountered several times.

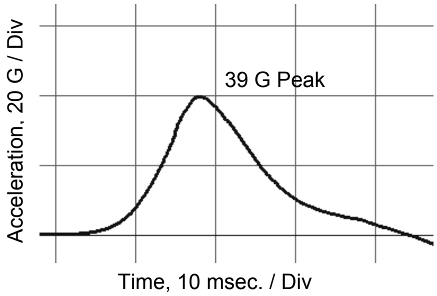
A packaging supplier was given a contract to design and furnish a protective package. A major portion of the performance requirement was that the package should transmit no more than 40 G to the product during a specified drop test. The product was a device with a number of moving parts and flexible interior components. The package was designed, and several prototypes delivered to the customer. The customer put a product in the package, dropped it from the specified height, and obtained the unfiltered data shown below. The measured peak acceleration was 56 G; the customer called the supplier to say that the package failed to meet requirements, and that the contract was therefore being cancelled.

Unfiltered Shock Pulse,
Package with Actual Product



But the supplier had also done drop tests, and their data looked like this:

Unfiltered Shock Pulse,
Package with Dummy Product



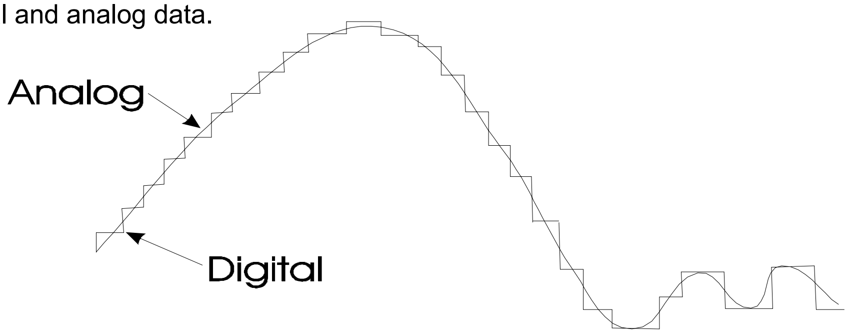
The difference? The supplier didn't have a product available, so used a dummy of the same size, shape, weight, and center of gravity – but made from solid wood. The supplier's pulse was a true indication of the pulse transmitted by the cushion to the product; the customer's pulse showed high-frequency noise, generated by the movement of product components and product flexibility, and picked up by the accelerometer. When the customer properly filtered their data to remove product effects, they obtained a pulse similar to the supplier's. The contract was reinstated.

It wasn't that the customer's data was incorrect per se, it was just that the contract was based on the *shock transmitted by the cushion to the product*, and the noise generated by the product component responses was not the supplier's responsibility nor subject to their control. The supplier's frequency of interest, and the one implied by the contract, was the principle pulse frequency. Proper filtering removed the noise, and allowed accurate measurement of the principle pulse. The customer, on the other hand, might be *very* interested in those product responses, and might modify the product design, the contract, or both as a result. But, as originally specified, the supplier met the contract performance requirements.

Readout Devices, Data Systems

As discussed above, essentially all acceleration data systems in the modern package testing laboratory are computer-based. This means that the acceleration signal, after being conditioned, is connected to a high-speed analog-to-digital converter (A/D), converted to digital data, and sent to the computer. There are two issues relating to A/D conversion that are of interest to us as users: the number of bits of resolution, and the sampling rate.

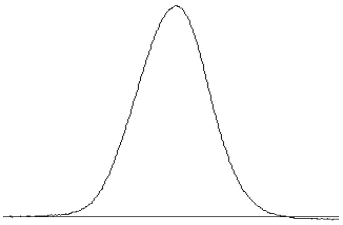
Bits of resolution. The analog signal, before being converted to digital, has an infinite number of possible levels, or amplitude values. But digital data is represented by numbers, so after A/D conversion there are a finite number of discrete steps possible. Since computers operate on the binary number system, these steps are based on powers of 2. The number of bits (*bi*nary digi*ts*) of resolution determines the size of the discrete steps. For example, in an 8-bit system, any signal can only be represented by one of 2^8 levels, or 256 possible levels. A 16-bit system has 2^{16}, or 65536 possible discrete levels. The figure below shows the difference in representation of digital and analog data.



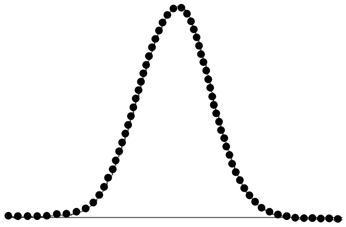
With more possible levels, the data can be more accurate. There are several other factors which influence accuracy, but in general better data is delivered by systems with higher bits of resolution.

Sampling Rate. A/D converters actually take samples of the incoming signal at discrete intervals of time. Usually this is very fast, perhaps thousands of samples per second, but it is never fast enough to totally describe the time variability of the incoming data. There will always be something happening during the time between samples, and the computer device cannot see this portion of the data. The result may be distortion of the converted signal and potential error. In the vibration data systems we use in packaging laboratories, the sampling rate is automatically adjusted to minimize errors. But with our typical shock data systems, an operator sets the sampling rate (or some other parameter which determines the sampling rate), so the possibility exists that excessive errors can be created.

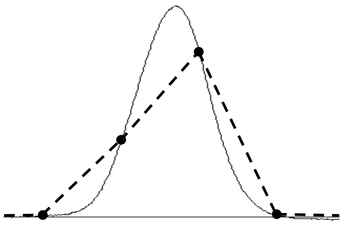
In the figure at the left below, the smooth light line represents a shock pulse to be measured. In the next figure, the dots represent the A/D samples of that data. If the samples are very close together as shown, the computer gets a good representation of the waveform, and is able to accurately determine the peak amplitude, duration, and other parameters (in most typical cases, the dots (samples) are actually many times closer together than what can be drawn here). But it is possible to inadvertently create a situation as shown on the right – here the dots are not close enough together, relative to the duration and shape of the pulse – to give an accurate depiction. With so few dots, the computer may calculate that the peak amplitude is very much lower than it actually is, and that the waveform is distorted as shown by the dotted line.



Shock Pulse



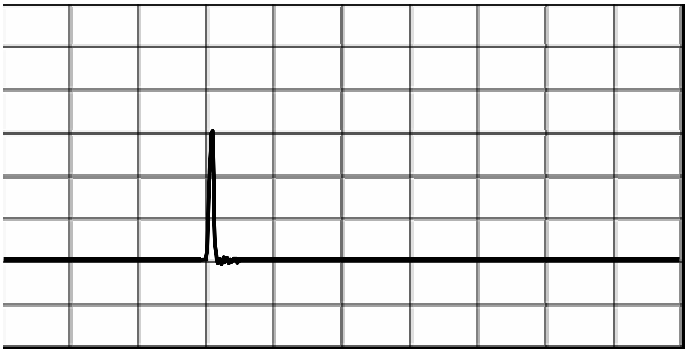
Adequate Sampling



Sampling Rate Too Low

The way this typically appears on the data system's screen is shown below. When only a very narrow "spike" of data appears, it may be that the sampling rate is too low for that shape and duration of pulse. It is generally recommended that the pulse width be a *minimum* of ¼ to ½ division on the screen for best accuracy.

Actual Appearance of Potential Inadequate Sampling Rate Problem



If the data system has a "zoom" function, it may be possible to expand the display and make a determination about the sampling rate error. If the zoomed "pulse" shows less than approximately 10 to 20 steps, dots, or straight line segments (depending upon how the system displays data), there may not be enough samples for reasonable accuracy.

Data System Functions. Once the signal is digitized and stored in memory, the data system computer program performs various display and analysis tasks. Vibration data computers calculate sinusoidal frequencies and amplitudes, Power Spectral Density (PSD)[6] information, and present comparisons (called transmissibility plots) of signals from multiple accelerometers which may be mounted on the test specimen. It is very useful to plot the response of a product or component to input vibration, as a means of identifying natural frequencies and amplifications at resonance. Shock data computers typically calculate the basic pulse parameters of acceleration, duration, and velocity change, but often also are able to compute deflections, triaxial resultants, rotational shock, Shock Response Spectra (SRS)[6], Fast Fourier Transforms (FFT), and more. Even relatively inexpensive systems are able to deliver a broad range of advanced functions, reflecting the power and economy of modern personal computers.

CONCLUSION

Although determination of pass or fail is certainly the first priority of package performance testing, instrumentation of the test item can yield vital data which would not otherwise be obtained. The margin of pass or fail can be quantified, information regarding product and component responses can be obtained, findings can be fed back to the product and package design process, and ISTA's vision of the "Just Right Transport Package" can be efficiently realized. But instrumentation must be selected, configured, applied, and operated correctly to ensure accuracy and meaningful results. It is hoped that the information in this paper will help to further understanding and use.

REFERENCES

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2. ISTA's "Vision".
3. ASTM D6537, "Standard Practice For Instrumented Package Shock Testing…", American Society for Testing and Materials, 100 Barr Harbor Dr., West Conshohocken, PA 19428, www.astm.org.
4. Some examples of accelerometer and signal conditioner information may be found at www.pcb.com, www.kistler.com, , www.endevco.com, www.columbiaresearchlab.com, and www.dytran.com.
5. From the ISTA Certified Packaging Laboratory Technician program materials, originally authored by Dennis Young.
6. "PSD & SRS in Simple Terms", W., I. Kipp, presented at International Safe Transit Association's ISTA Con 1998, Orlando Florida.