

Effects of shocks and vibrations on products and packaging

A variety of factors can cause damage to products during transport: temperature, humidity, vibrations, and shocks. Here, we will only be covering damage due to vibrations and shocks.

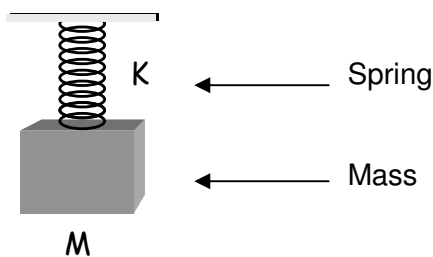
Introduction

A certain basic level of knowledge is required in order to gain insight into why products break during transport. This basic knowledge is the theory behind shocks and vibrations. This basic knowledge of shocks and vibrations can explain the damage. The theory discussed below can shed light on concerns such as “we used double packaging and it still got broken”.

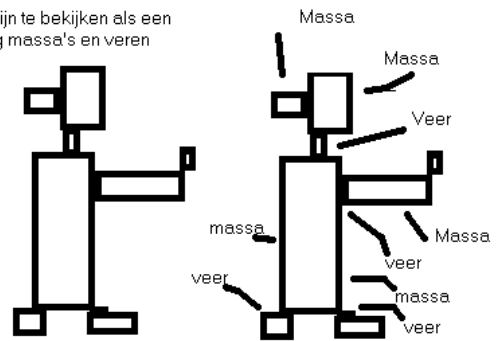
Spring-mass system

All of the parts in a product can be regarded as a spring-mass system, a collection of masses and springs. Some are rigid and others are quite flexible. A packaged product can also be regarded as a spring-mass system. This approach allows us to examine the basic effects of shocks and vibrations.

Vibrations



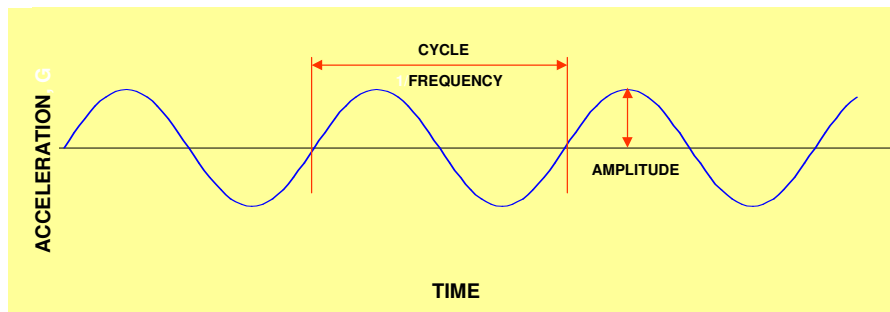
Producten zijn te bekijken als een verzameling massa's en veren




To get a better idea of why a vibration causes damage, we will first look at the basic principles of vibrations.

What does a vibration look like in a graph and what units are used to measure it?

If we set a spring-mass system into motion, then we see that the mass is displaced from one side to the other over a certain period of time. We can illustrate this in a graph with the horizontal axis representing time and the vertical axis representing the displacement or acceleration of the mass.



We can now perform a simple calculation to determine how many times a second the mass moves back and forth. We call this the frequency. If you go to the lavatory four times in one hour, then the frequency is 4/hour. Instead of hours, we will be using seconds. If the mass moves back and forth 10 times in a second, then it has a frequency of 10/sec, or 10 Hz, named after a Mr. Hertz.



In formula form $f=1/t$
f is frequency in Hz
t is time in seconds

A product's response to a vibration

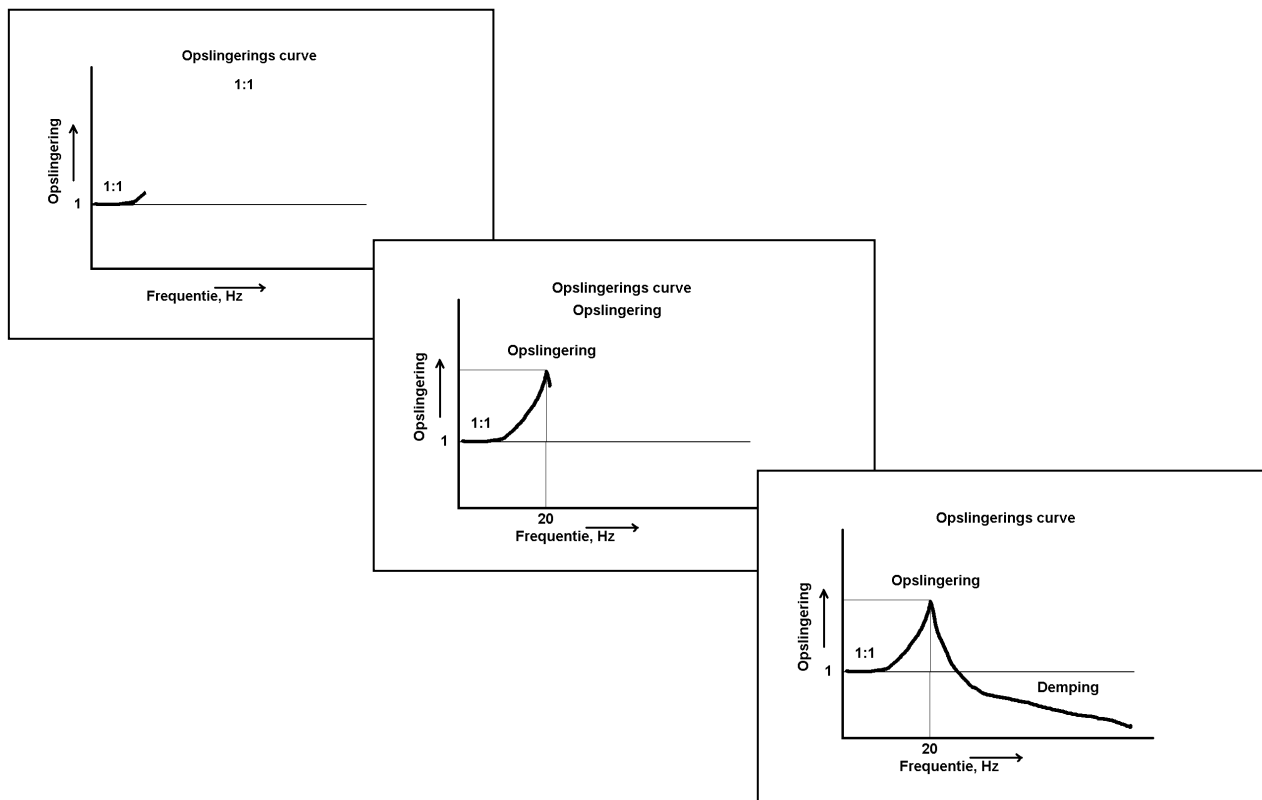
One property of a spring-mass system is that its oscillation speed (frequency) is always the same. As long as nothing changes with respect to the mass or spring, the combination will have the same natural frequency. This fact has a lot of explanatory power.

If a spring-mass system is forcibly set into motion, then we have three possible final outcomes:

- the mass moves along with the excitation
- the mass moves more than the excitation
- the mass moves less than the excitation

We can demonstrate this in an experiment, for instance, with a piece of elastic, a spring, and a mass, such as a set of keys.

If we gradually increase the excitation from a low frequency to a high frequency and measure the mass's response, then we can calculate the transfer function. The transfer function is the quotient of the response and the excitation. We divide the response by the excitation. For example, if the mass displaces twice as fast as the excitation (2/1), then the transfer function is 2. If we make this calculation at each frequency and plot all of these points in a graph, then we get a line as shown in the figures below:



The highest point of the resonance curve is also called the resonance frequency.

Why vibrations break products

We have seen that the mass undergoes the greatest amount of displacement during resonance. If the product is subject to constant vibration during transport, this will cause fatigue. The degree of displacement is a crucial factor here.

We can demonstrate this using a paper clip. First, we unbend the paperclip into a straight rod. If we hold the rod by its end, then we can bend it back and forth either:

Slightly- the paperclip will not break quickly

Or far (all the way to one side, then the other) - the paperclip will break after a few bends

So, it appears that there is a relationship between how far you bend the paperclip and the number of times (frequency) that the paperclip can be bent.

That precisely is the failure mechanism for vibrations. We have a resonance, large displacement, and regularity of displacement, which often result in fatigue failure.

What can you do about vibrations?

At the risk of stating the obvious, try to prevent vibrations. If there are resonances, try to keep these resonances outside of the range of the most powerful excitation. Measurements have shown that the highest vibration levels during lorry transport are between 4 and 16 Hz. The natural frequencies of products and packaging should preferably be outside this range.

Shock

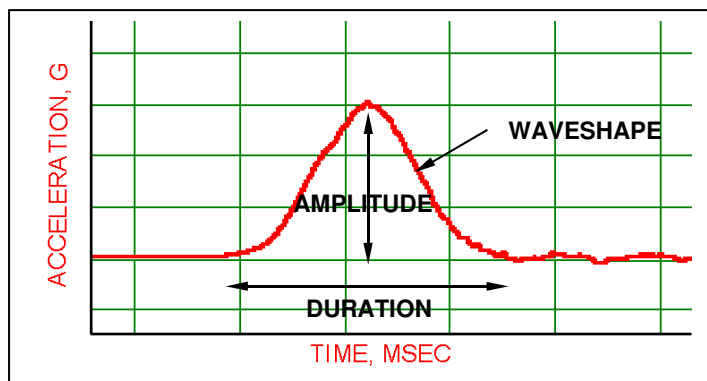
Shocks are not very different from vibrations, but shocks often only occur once. The basic principles are practically the same as for vibrations. However, there is a minor difference in the failure mechanism.

What a shock looks like in a graph, and what units of measurement are used

The shock pulse shown below looks like a vibration in disguise. Multiple consecutive shocks could be a vibration. If we take the spring-mass system again and give it a smack, then it will move far once and then vibrate out.

The pulse is shown as a function of time (t), the horizontal axis, and acceleration (a), the vertical axis. As time advances, acceleration increases up to a maximum, after which it decreases. The pulse's maximum point often called "so many [g]", or better $[m/s^2]$. However, this value does not indicate how long the acceleration lasted.

Just like vibrations, a shock pulse has a frequency, which can be calculated in the same manner. The figure shows half of a sine wave, so the frequency of a shock pulse is:





In formula form $f=1/2t$
f is frequency in Hz
t is time in seconds

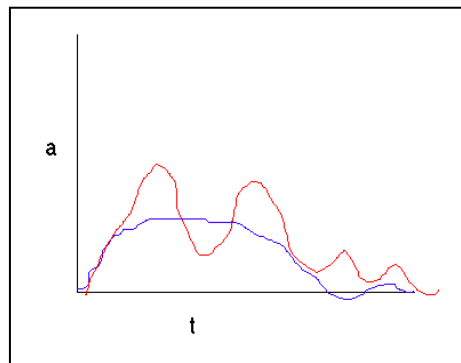
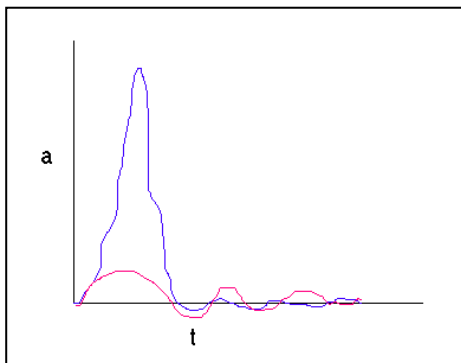
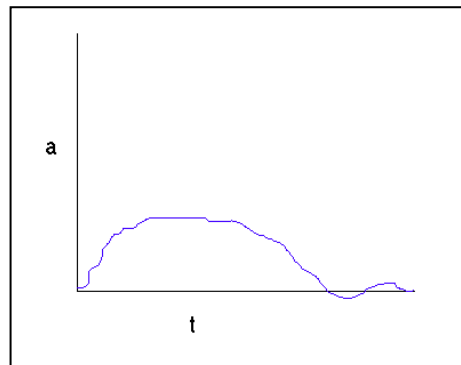
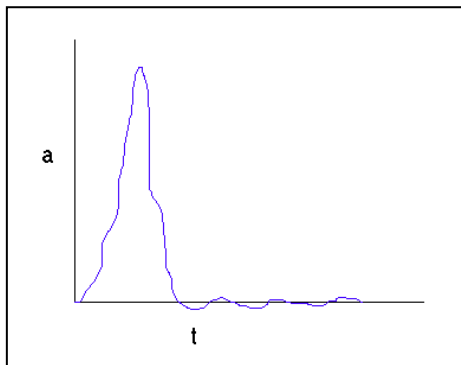
Here, we multiply time by two because the shock shown in the figure is a half sine wave. All of this may be a bit technical, but what it boils down to is that a shock has its own natural frequency just like a vibration does.

A product's response to a shock

Acceleration, which has received a lot of attention, is not actually the most important component of a shock. As we have seen with vibrations, a spring-mass system responds to a certain excitation frequency. This is also the case with shocks.


For instance, if you smack the table with your hand, this may register as much as 1,000 [m/s²] (1 g = 9.81 m/s²), but in all likelihood the table will not break. If the pulse had lasted a bit longer, say a few seconds, then the table would have broken. This shows that it is not only the acceleration that matters, but also the duration. The two figures below show two different pulses. The first pulse has a lot of acceleration but a short duration, and the second one has little acceleration, but a long duration.

The first pulse has a high frequency and the second pulse has a low frequency. A spring-mass system's response to this pulse will depend on its natural frequency.



The red lines in the figures below shows how a mass-spring system might respond to the two pulses.

The natural frequency of a product or packaging will determine whether or not it responds to the shock pulse. If the frequency of the shock pulse is the same as the natural frequency of a



product or packaging, then the product or packaging will respond to it, just like with vibrations. You can see that the resonance of the spring-mass system in figure two is higher than in figure one. In spite its lower acceleration, the second pulse will probably break the product.

In order to compare these two pulses, we have to look at their areas. The area is equal to the rate of change in speed Δv (Δv) in [m/s]. The rate of change in speed is also the drop (energy).

In mathematical terms, acceleration is integrated into time: $f(a)d(t)$ gives us the speed. A high acceleration with a very brief duration will result in a low rate of change in speed, and so may not cause immediate damage.

In sum: a shock pulse is defined by two values, acceleration [m/s^2] and duration [ms]. The “energy” of the rate of change in speed [m/s] can be determined by this acceleration and duration. The rate of change in speed is a measurement of the shock’s potential for damage.

Why shocks break products

A shock is one-off. Just as with the paperclip vibration experiment, the shock involves displacement, but it is also a matter of the energy contained in the shock (rate of change in speed). This is explained below.

Products can be roughly divided into two groups: tough products and brittle products. Tough, elastic products have a higher ductility or yield point than brittle products. Tough products include steel, many plastics, and fresh wood. Examples of brittle products would be ceramics, concrete, glass, and old wood. An elastic band can absorb energy well, but a piece of concrete less so. (You’d rather jump onto a sofa than onto the street: the sofa will absorb the energy of your fall; the street won’t.)

Because a shock will suddenly introduce an amount of energy (rate of change in speed) into the product, the degree of energy absorption, called the ‘elasticity’, will determine whether or not the product will break.

To sum up, the failure mechanism for shocks is displacement (response), just like for vibrations, and the capacity to absorb energy, or elasticity.

In the real world

Now that you are familiar with the theory, a great deal of damage can be avoided. Suppose you double-package a product in the softest, most elastic packing material that you could find, but it still breaks. How is that possible? Evidently, you have made the packaging (the spring) and the product being transported (mass) into a spring-mass system whose natural frequency is exactly the same as the excitation frequency of the means of transport. Also, if the product has parts that resonate at this frequency, large displacements will occur and the damage will be obvious.

A is acceleration in m/s^2 , F is force in newtons

In conclusion, we would like to discuss a complaint that a lot of people have about g forces. This is not a good name because, as we have seen, acceleration is cited in [m/s^2]. A force F would be in newtons. So there is no g force. Nevertheless, the formula $F=m*a$, allows us to multiply the mass by the acceleration in order to get the force.