Tech Note 6

22apr13

Sensor Minimum Discernable Signal
And
Determining Field Data and Lab Particle Velocities

Sensit here proposes a standardized method of comparing minimum detectable signals across all saltation sensor manufacturers. Basically a measurement of how much energy transferred from a saltating particle impact is required to trigger a response from a saltation sensor. The standard unit of N-m is suggested.

Note: A saltation sensor whose detection circuitry is subject to the electric charge of a saltating particle has no possibility of response standardization.

The minimum particle impact energy transferred to the sensor (via particle deceleration) that is required to trigger the sensors electronic circuitry can be thought of as the sensor's minimum discernable signal, or a universal minimum response reference for all impact saltation sensors.

A particle velocity (10 times U^*_t where U^*_t = 20 cm/s[z_{10cm}]) of 200 cm per second is reported [Owen 1969] to be the velocity at the start of movement as a general rule. Particle diameter can be assumed to be 100 microns as described by Owen [1969] and Bagnold [1941] as the predominate diameter to move at the start of movement (threshold of movement).

However, Sensit uses glass spheres of 600u and 1000u in diameter for testing and calibration because they are much easier to work with and will be in the non-Stokes region over a longer drop length (release height) than 100u diameter spheres. A glass sphere of 100u diameter is only in the non-Stokes region for a release height of ~1 cm. The larger 600u and 1000u spheres can be released at ~3 to 5cm however Sensit believes it is acceptable to release the larger particles at a maximum release height of 60cm. Drag is starting to have an effect on particle velocity at this height making the following method of calibration slightly inaccurate.

For the sake of simplicity and measurement consistency we are willing to accept this calibration method as a rule of thumb for standardization purposes. In reality, a perfectly calibrated sensor producing an absolute value *in correct units for particle impact energy is not possible or practical. This is because saltating particles are not uniform in shape, density or spin. An impact from a soil particle aggregate may deplete some of its energy destructing upon impact. Irregularly shaped particles may transform some of its energy into spinning the particle upon impact.*

The energy transferred from 600u and 1000u diameter spheres is much greater than 100u diameter spheres. This is favorable for testing purposes because saltating particle velocities are much greater than free-fall velocities. We can achieve the impact energy of 100u diameter particles traveling at higher speeds in a drop test by using larger particles (600u & 1000u) traveling at a slow speeds while the drag coefficient remains in the non-Stokes region longer than the smaller particles.

Sensit suggests an electronic specification for impact sensor detection threshold to be *work* done or *energy transferred* necessary to cause a sensor response in units of ergs (FYI; erg = 10^{-7} joule).

The use of particle velocity for a given particle mass (or inversely) as a specification standard presents non-linear values when comparing sensors. Example; Assume, for a given mass that one sensor has its detection threshold in terms of speed at 10m/s, the other at 20m/s. It may be natural to immediately assume one is twice as sensitive as the other. In reality, the first sensor is four times as sensitive.

The energy transferred to the sensor will always be the particles energy prior to impact minus the particles energy after the impact. The particle will have some velocity after impact. The sensor does not receive all the particles kinetic energy thus further complicating any form of absolute calibration. Potential energy is always preserved.

Kinetic Energy Threshold Calibration

The *translational kinetic energy* (E_k) of an object is related to its momentum p(mv) as:

E_k = p2 / (2 m) = (m^2 x v^2) / (2 m) = ½ m v^2

KE (energy of motion) is defined as *the **work** needed to accelerate a body of a given mass from rest to its current velocity.* Or conversely, the work (energy transferred by force) used to decelerate the particle upon impact with the sensor's surface which is our sensor's response. Having gained this energy during the particle's acceleration via the driving force of the wind, the body maintains its kinetic energy unless its speed changes. Negative work of the same magnitude would be required to return the body to a state of rest from that velocity.

Particle Kinetic Energy Example

Particle: 100 micron diameter (4/3 pi r^3, den=2.5)
Mass: 5.48^{-12} g
Velocity: 18 meters per second (40 mph)
E_k = ½ x 5.48^{-12} x 18^2 = 1.78^{-9} joules
Or since 1 erg = 10^{-7} joules, E_k = 1.78^{-2} erg.

(Wikipedia) definitions:

Energy is a concept that relates to the capacity of matter to perform work, the result of its motion.

Work ($W = Fd$, joules) is the amount of **energy** transferred by a **force**. Like energy, it is a scalar quantity, with units of **joules**.

Force - Force is mathematically defined as the rate of change of the **momentum** of the body. Since **momentum** is a vector quantity (has both a magnitude and direction), force also is a vector quantity. (Wikipedia)

F = *d*P / *d*t rate of change of momentum which also equals

F = m*a mass times acceleration (In the case of constant mass, and velocities)

If a system is in equilibrium, then the change in momentum with respect to time is equal to 0:
F = *d*P / *d*t = ma = 0

Acceleration ($m \cdot s^{-2}$) is defined as the rate of change (or derivative with respect to time) of **velocity**. It is thus a vector quantity with dimension length / $time^2$. In SI units, acceleration is measured in ($m \cdot s^{-2}$) using an accelerometer. (Wikipedia)

Joule - One joule is the work done, or energy expended, by a force one newton moving an object one meter along the direction of the force. This quantity is also denoted as a Newton-meter with the symbol N·m. (Wikipedia)

$$1\,\mathrm{J} = 1\,\mathrm{kg} \cdot \frac{\mathrm{m}^2}{\mathrm{s}^2}$$

Dynes - The **dyne** (symbol "dyn") is a unit of force specified in the *centimeter-gram-second* (cgs) system of units, a predecessor of the modern SI. One dyne is equal to exactly 10^{-5} newtons. Further, the dyne can be defined as "the force required to accelerate a mass of one gram at a rate of one centimeter per second squared." (Wikipedia)

Units	Newton (N) = 1 kg·m/s²	(old cgs system)
	Dyne(dyn) = 1 g·cm/s²	(new SI system)
	Dyne(dyn) = 10^{-5} Newtons	(new SI system)

Collisions - There are two basic kinds of collisions, both of which conserve momentum:

Elastic collisions conserve kinetic energy as well as total momentum before and after collision. (Wikipedia)

Inelastic collisions don't conserve kinetic energy, but total momentum before and after collision is conserved. (Wikipedia)

Testing the Kinetic Energy Sensor's Sensitivity

Start a simple test by dropping a glass sphere on sensor from a glass plate. Note the release height. This method is especially good for the new FP5 Flat Plate sensor as well as the standard H11-LIN model.

If the release height is insignificant, where the falling particle remains in the non-Stokes region, the **kinetic energy** transferred to the Sensit surface can be considered to be equal to the **potential energy** times a velocity determined by the acceleration of gravity. This is done by multiplying the height of the mass times the gravitational constant:

PE = m $dZ\, g_0$ = mass x height x acc.grav. (g_0) = KE

m(gm) = 4/3 pi (d^3/8) x density

dZ = distance of fall (change in height)

$\boldsymbol{g_0}$ = 980 cm/s (gravitational acceleration)

Particle velocity for a particle drop test

Start with smallest diameter, increasing distance, stop when the sensor responds.

Particle velocity for field data

The value for particle velocities used for field data is based on the assumption that the particle velocity is *proportional* to the driving force of the wind. This proportionality claim is generally accepted and is essential for an estimation of particle velocity for each data point.

For field data, the only information we have that relates to particle velocity is the driving force of the wind which is ultimately responsible for particle movement.

It is also generally accepted (without getting into heated discussions of details and semantics) to relate U* (shear stress of the wind) to particle velocity. Dr. P.R. Owen, through extensive wind tunnel testing and modeling arrived at a rule of thumb to roughly estimate particle velocity in terms of our friend U*.

His statement for a rough estimate of particle velocity (Pv_{z10cm}) goes as; P_v (cm/s) = 10 times U*(m/s). Example: If U* = 30 cm/s then particle velocity ~3 m/s at Owen's assumed height of 10cm. Dr. Owen's estimation always assumes a particle height of 10cm.

At this point, our velocity calculation does not have a valid unit definition because our sensor height may not be 10cm as needed for Owen's estimation. Fortunately this doesn't matter. We are relying on the assumed relationship; *proportion* ($P_v \propto U^*$) to process the field data. The proportionality of particle velocity to U* allows the KE data to by modified by a squared term, i.e. the slope of the log scale in U*.

Now we solve for mass from KE ($1/2\ mv^2$) data using the above estimation of particle velocity.

Keep in mind, at this point we still have not valid units for mass but we know the processed value is now a value proportional to mass.

Convert our values of quasi mass to a valid unit of grams.
We now calculate a field data conversion constant by dividing the total catcher mass (for a given event) by the total number of preprocessed Sensit KE values. This provides a conversion for a KE_{output} value of 1 to mass in grams that is portioned to mass via the driving force of the wind U*.

The last step is to multiply each processed Sensit KE data point by the field calibration constant. The Sensit data with consideration for the data loggers sampling interval now reflects mass flux.

Determine the mass of the sphere:
m = 4/3 pi d^3

Correct the units:
d = 100 microns = 1062 x 10^{-4} = 10^{-2} cm

Energy - Dropping Mass

Potential Energy

mgh = mass x gravity x height
units : gm cm/s^2 cm = gm x cm^2/s^2 = mass v^2

Kinetic Energy

mass = height x weight[grams]

weight = mass x gravity
units = grams x grams x cm / s^2