Application Note A

Fundamentals of Non-Contact Speed Measurement Using Doppler Radar

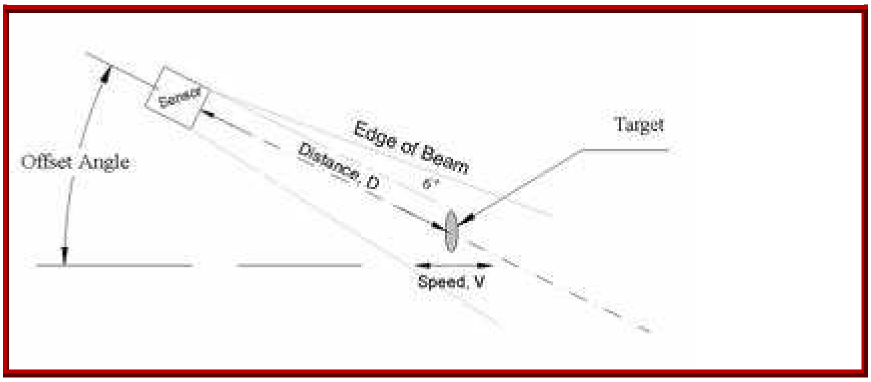

Figure 1 - Non-Contact Speed Measurement

Doppler Shift Frequency

Non-contact speed measurement using the Delta speed sensor is achieved through the use of Doppler Radar. Doppler radar is named after the Doppler principle, which explains the frequency shift associated with energy waves reflected by or emanated from a moving body. A familiar example of a Doppler shift is the change in pitch when a car passes - higher in pitch as the car approaches, lower in pitch as it leaves.

In the case of the Delta speed sensor, a Ka band radar signal is transmitted at a specific frequency by the sensor, reflects off of a target (or targets) and returns to the sensor (see Figure 1). If either the sensor or the target are moving relative to one another, the signal will be shifted in frequency when it returns to the sensor. This shift in frequency allows measurement of the relative velocity between the sensor and target.

The fundamental Doppler frequency shift is given by:

$$F_d - 2 * V * \left(\frac{F_0}{c}\right) * \cos\theta$$

where:

Fd = Doppler Shift, Hz
V = velocity
θ = offset angle of sensor relative to direction of target motion
c = speed of light
Fo = 35.5 ± 0.1 GHz (Ka Band)

For the Delta speed sensor, the *Doppler shift* is 105.799 ± 0.298 Hz/mph (65.74074 ± 0.185185 Hz/kph). The Delta speed sensor's output is a square wave which is 100 Hz per mph (62.138 Hz per kph).

Correction for Offset Angle

As shown by the Doppler frequency shift equation, any offset angle (see Figure 1) between the center of the radar beam and target direction of travel will introduce a factor of cosine θ into the measured speed. This means that the output of the sensor must be corrected by dividing into it the cosine of the offset angle as shown in this example:

case 1: Sensor Output: 2600 Hz Offset Angle, θ = 30°
Actual velocity = (2600 Hz / (100 Hz/mph)) / cos 30°= 30.02 mph
case 2: Sensor Output 2600 Hz Offset Angle, θ = 31°
Actual velocity = (2600 Hz / (100 Hz/mph)) / cos 31°= 30.33 mph

Also shown by this example, changes in offset angle influence speed measurement. It is recommended that the angle be known to at least 1°to maintain an uncertainty of 1 to 2% for a target in the centre of the beam. Because the value of the cosine changes rapidly for offset angles about 45°, these angles are not recommended.

The radar beam diverges about 6°from centre resulting in a roughly conical shaped beam (think of it like the beam of a flashlight). In the case of a target passing a fixes sensor, this geometry can introduce what is termed *cosine error* into the speed measurement. This happens because targets at one edge of the beam are at a different offset angle than in the centre of the beam. For small offset angles, the cosine change from one edge of the beam to the other is small and so the cosine error is minimal. For larger offset angles, the change is more significant. In the case of vehicle ground speed measurements where the sensor is used to measure the speed of a surface relative to the sensor, cosine error generally produces a steady bias. Refer to Application Note B - Using Non-Contact Speed Sensing to Measure Vehicle Ground Speed for more information on correcting for cosine error bias. For a method of correction that corrects for both offset angle and cosine error at the same time, refer to Application Note C - Distance Applications Using the Non-Contact Speed Sensor.

Signal Strength and Multiple Targets

The Delta speed sensor includes a signal processing algorithm that determines the strength of return signal from the target. If the signal is strong enough, the output is turned on, and the sensor is said to be “locked”. Because different targets reflect different amounts of the radar energy back to the sensor, the sensor will lock at different distances from the target depending on such factors as the size, material and orientation.

In general, large targets reflect more energy, and the sensor will be able to distinguish them at a greater distance. Highly reflective targets, such as metal, will reflect more energy than materials like wood or plastic. If the target is a large flat, reflective surface, it will reflect a large amount of energy back to the sensor if it is oriented perpendicular to the beam, but much less energy if it is at an angle.

A useful analogy for deciding the amount of reflection in many cases is to think of the sensor as a flashlight. If the target surface would reflect a large amount of light back to the sensor, it is probable that it will return a strong signal. (Remember, however, that radar energy is at a different wavelength than visible light and the analogy will not work in some cases!)

The sensor receives reflected energy from all possible targets within the radar beam. If any of the targets are moving, it will cause a Doppler shift, possibly causing a false measurement if it is not the desired target. For this reason, it is important to consider the beam geometry, particularly the divergence angle, and make sure that the sensor cannot “see” non-targets.