



Temperature sensors and cables

Number and placement are important to effectively monitor stored grain

Editor's note: This is the first in a series of articles on grain storage management.

by Dirk Maier and Jordan J. Wright

Monitoring the temperature, moisture content and carbon dioxide (CO₂) levels in stored grain is essential to maintaining quality. Aeration with ambient air is the most common method used to manage grain temperature, moisture content, and CO₂ levels. Still, the complexities of stored grain ecosystems make effective monitoring and optimal management challenging, especially as storage bins increase in size. Temperature and relative humidity sensors installed on cables and placed in the stored grain mass are routinely used to track grain mass temperature and moisture content. Carbon dioxide sensors can be placed in the plenum and headspace below and above the stored grain mass to track the onset of spoilage due to biological activity from molds and insects.

The number and placement of sensors, and the interpretation of sensor readings are key to effectively monitoring conditions in a stored grain mass and managing optimal windows of aeration based on real-time weather data. This first article in this series focuses on temperature sensors and explores the number needed on a cable as well as cable placement to effectively monitor the quality of stored grain.

Temperature sensors and cables

Temperature sensors used for stored grain monitoring consist of either thermocouples or thermistors. According to manufacturers, type "T" thermocouple (TC) sensors are commonly used to manufacture TC-based temperature cables for stored grain monitoring applications. Type "T" thermocouples consist of one copper wire and one wire made of con-

stantan, an alloy approximately 57% copper and 43% nickel.

The junction of the two wires is the actual temperature sensing point, which is rated up to 600°F (315°C). Depending on duty level (i.e., tensile strength) and customer preference, sensor points are spaced 3, 5, 6, 7 or 8 feet (0.9, 1.5, 1.8, 2.1 or 2.4 meters) apart in wire bundles inside heat-shrunk vinyl or nylon sleeves. These are placed along a load-bearing steel rope and extruded together inside a vinyl or nylon outer jacket (see Figure 1, page 71).

Together with the lead wire they make up a temperature cable that can be installed once it is cut to the correct length and fitted with hanging hardware. Lead wire carries the thermocouple voltage signals from each cable to a multiplexing junction box that can convert analog into digital signals. Lead wire consists of groups that contain a common constantan wire and typically six copper wires that are dedicated to each individual thermocouple within the cable.

Thermistors are temperature sensors whose electrical resistance changes in response to a change in temperature. According to manufacturers, Negative Temperature Coefficient (NTC) thermistor sensors, which exhibit a decrease in resistance as temperature increases, commonly are used to manufacture thermistor-based temperature cables for stored grain monitoring applications. They are produced using powdered metal oxides that determine their electrical characteristics.

NTC thermistor sensors have a non-linear temperature versus resistance relationship and are capable of measuring temperatures up to 572°F (300°C). They are generally very rug-

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GRAIN OPERATIONS

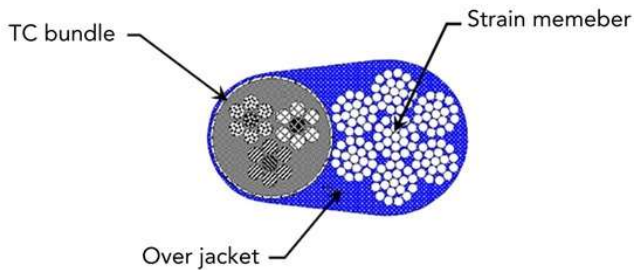


Figure 1.

ged, extremely stable, and highly accurate devices. Depending on duty level (i.e., tensile strength) and customer preference, sensor points are spaced 4 or 8 feet (1.2 or 2.4 meters) apart on a digital sensing cable placed inside a sturdy outer tube. This allows the temperature-sensing element to be retracted if it needed to be replaced in the future.

The outer tube contains two co-extruded load-bearing steel ropes. The cables must be manufactured to the correct lengths and fitted with hanging hardware. Lead wire carries the thermistor voltage signals to a multiplexing junction box that converts analog into digital signals. From there, signals can be transferred wirelessly to digital monitoring and fan control platforms.

Cable placement

Temperature cable manufacturers specify placement of cables in the grain mass as a function of bin diameter. For example, the installation manual of Boone Cable Works & Electronics, Inc. (BCWE) specifies one cable in the center of a 20-foot (6.1 meters) diameter silo, three evenly-spaced cables at a radius of 9 feet (2.7 meters) in a 36-foot (11-meter) diameter bin without a cable in the center, and four evenly-spaced cables at a radius of 14 feet (4.3 meters) in a 42-foot (12.8-meter) diameter bin with a fifth cable in the center.

OPIsystems Inc. recommends the same number and placement of cables for bin diameters up to 42 feet (12.8 meters), specifying that one cable in the center suffices for silos up to a diameter of 24 feet (7.3 meters). For bin diameters of 60 feet (18.2 meters), BCWE specifies 11 cables with none in the center, three placed evenly spaced at a radius of 8 feet (2.4 meters) and eight placed evenly spaced at a radius of 23 feet (7.0 meters). That places the outer cables 7 feet (2.1 meters) from the bin wall.

For the same bin diameter, OPI specifies eight cables with one in the center and seven placed evenly spaced at a radius of 20 feet (6.1 meters). That places the outer cables 10 feet (3.0 meters) from the bin wall. For bin diameters of 90 feet (27.4 meters), BCWE specifies 18 cables with one in the center, six placed evenly spaced at a radius of 18 feet (2.4 meters), and 11 placed evenly spaced at a radius of 35 feet (10.7 meters). That places the outer cables 20 feet (6.1 meters) from the bin wall.

For the same bin diameter, OPI specifies 19 cables with one in the center, six placed evenly spaced at a radius of 18 feet (5.5 meters), and 12 placed evenly spaced at a radius of 36 feet (11 meters). That places the outer cables 18 feet (5.5 me-

ters) from the bin wall. No explanation or supporting documentation is provided by either company (nor other companies that manufacture and/or sell temperature cables for that matter) as to why in one case a cable placed in the center plus seven 10 feet (3.0 meters) from the wall supposedly provides temperature monitoring as effectively as three cables placed 8 feet (2.4 meters) from the center plus eight cables 7 feet (2.1 meters) from the wall in a 60-foot (18.2-meter) diameter bin. Or, why in a 90-foot (27.4-meter) bin 11 cables placed 20 feet (6.1 meters) from the wall supposedly provides temperature monitoring as effectively as 12 cables placed 18 feet (5.5 meters) from the wall.

Similarly unexplained is the claim by some temperature cable providers that a temperature cable can monitor grain within a radius of 9 feet (2.7 meters), or that certain temperature cable placements will allow for monitoring certain volumetric percentages of the grain mass.

The 9-foot (2.7-meter) radius claim appears to ignore the vertical spacing of sensors that on typical cables is 6 to 8 feet (1.8 to 2.4 meters). Additionally, spherical monitoring volumes cannot be efficiently packed into a cylindrical grain mass with a coned peak. Some of the stored grain mass not included in the volumes will not be monitored at all, while some of the stored grain mass will be included in overlapping volumes. This would imply that certain overlapping grain volumes would be measured by multiple

A contrast between grain that is out of condition (top of photo) and grain in good condition at the bottom of the photo.



Photo courtesy of TSGC Inc.

nearby sensors, questioning the validity of the readings.

In fact, the true effective monitoring radius, diameter or volume for a sensor or set of sensors mounted on a cable placed in a grain mass actually depends on a number of factors that will vary during the storage season as well as whether the grain is aerated or not.

In one of our recent studies, we examined three temperature cable layouts. For a single cable in the center of the bin, reportedly 15% of the grain mass is covered. For three, evenly-spaced cables placed at one-third of the distance from the center to the wall, supposedly 50% of the grain mass is covered. In the case of one cable placed in the center and six evenly-spaced cables placed at two-thirds the distance from the center to the wall, supposedly 100% of the grain mass is covered.

Assuming temperature sensors are spaced 7 feet (2.1 meters) apart along the cables, for a spherical radius of 3.5 feet without overlap, the effective coverage of the grain mass would only be 1.5%, 4.6%, and 10.8% for the one-, three- and seven-cable configurations, respectively. If vertical overlap among the spherical volumes were double-counted, the percentages would jump to 9.6%, 28.7%, and 66.9%, respectively. These are still lower than the claimed values and would give a false sense of security to stored grain managers in terms of how quickly a temperature increase due to

mold spoilage, for example, would be detected.

To approach the claimed values, one would need to assume that each sensor covers a radius of 7.3 feet (2.2 meters), i.e., a spacing of 14.6 feet (4.4 meters), and that overlapping grain mass volumes would need to be double or triple counted. These assumptions would yield 15%, 45%, and 105% grain mass coverage, respectively. Obviously, double and triple counting certain grain mass volumes would be considered unrealistic for effective monitoring by stored grain managers, nor are cables viable commercially with temperature sensors spaced that far apart.

Summary

Monitoring grain during the cool-down (aeration) and storage (non-aeration) periods using temperature sensors is critical for managing and maintaining quality. However, the documentation for recommending the number of sensors on a cable and the number of cables and their placement in a grain mass is not readily available. We will further review the importance of both in the second part of this article. WG

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