Hazard Monitoring Equipment
Selection, Installation and Maintenance

Johnny Wheat
4B Components Ltd,
East Peoria, IL, USA

Introduction

When selecting hazard monitoring equipment for bucket elevators and belt conveyors, there is a myriad of choices available. However, before you decide on the specific type of sensor and control you must first decide on what parameters you are going to monitor. On certain equipment there are laws and regulations that must be followed. OSHA Standard – 29 CFR / *Grain Handling Facilities – 1910.272* and NFPA 61: *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities* are two important US documents. However these standards should be used as a starting point for the minimum requirements. The plant manager or other responsible person should look at each piece of machinery individually and decide which additional areas need to be monitored and then look at other machines on the plant which may fall outside the scope of these documents but which should also be considered. Obviously budget constraints come into play and acceptable risk for the company and shareholders must be considered, however as with all insurance policies, you should not skimp and should purchase as much as you can afford. Typically the cost for hazard monitors is actually quite reasonable and is good insurance and a sound investment. Many companies will actually install sensors and controls on every piece of equipment in the plant. Unfortunately for many plants this is only done after the "horse has bolted", i.e. after a major disaster has occurred. Nowadays grain dust explosion reporting is a little more forthcoming and plant managers/grain companies are becoming more aware of the frequency of these events and the potential for disaster. Kansas State University maintains records of explosions reported within the industry (see table 1). Unfortunately these are only what are reported; many more explosions go unreported and still more events occur daily which fortunately do not result in explosions but do cause serious machine down time and lost productivity. Major education at expos and technical conferences does help to inform users of the hazards and make them more aware of the need to monitor the equipment and to be more comfortable with making not just the required investment but also going the extra mile. Some customers install monitoring equipment in stages and start by meeting the minimum requirements with carefully chosen equipment and systems that can be easily expanded at a later date to encompass other machines in the plant as further funds and resources become available. Once a decision has been made on which machines are to be monitored and which areas on those machines could cause danger, then the type of sensor and control system can be looked at. This paper will provide a guide to selecting equipment, taking into consideration these regulatory and practical factors.

Table 1. Agricultural Dust Explosions in the US (Source: KSU March 20, 2006 Report)

Year	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**Total**
Number	13	16	18	7	8	9	8	8	6	13	106

As with any type of electrical device used in an industrial environment, its usefulness, service life, reliability and also maintenance cost is very much dependent upon the quality of the initial installation. This is even more evident when we consider the unique challenges within the feed and grain industry. There are many outdoors applications where the equipment and installation must withstand harsh environmental conditions including wide ambient temperature fluctuation (–40º F to + 120º F), wind, rain, sleet, ice and snow. Sometimes seasonal workers and inexperienced employees have to work with and around the equipment. There can also be rodents around the plant, which could gnaw on cables causing maintenance problems with equipment. We will explore the practical implementation of installing hazard monitors in the harsh environment of the feed and grain industry so that they can be reliable and trouble free.

Once installed correctly the hazard monitoring system must be checked and maintained on a regular basis. The frequency of this testing is determined by the user taking into consideration the recommendations of the equipment manufacturer. Manufacturers of specific equipment usually have recommendations on how to maintain and how often to test equipment, however it is the user of the equipment who must ultimately decide on how frequent the tests and maintenance is to be carried out. High quality systems, which have been professionally installed, should not need a great deal of maintenance or periodic testing. However, external influences on the system can compromise even the most failsafe designs. As such, periodic system testing is extremely important and should be made a priority in any plant's preventative maintenance program. We will look at some important considerations with regard to maintaining hazard-monitoring equipment.

Equipment Selection

The tables and diagrams below are a guide to Occupational Safety & Health Administration (OSHA) and National Fire Protection Association (NFPA) regulations with regard to the monitoring of certain bucket elevators and belt conveyors. As discussed these should be the starting point and the minimum requirements for each machine.

Table 2.
Guide to OSHA and NFPA requirements for monitoring devices on bucket elevators

Hazard	**OSHA Requirement (See 1910.272 for full interpretation)**	**NFPA Requirement (See NFPA 61 for full interpretation)**
Belt slip	Motion detection device to provide a shutdown at 20% reduction in normal belt speed.	Same as OSHA, but also activate an alarm.
Belt misalignment	Belt alignment monitoring device, which initiates an alarm.	Belt alignment monitors at head and tail pulleys.
Bearing failure	Bearing temperature or bearing vibration monitors.	Same as OSHA.
Pulley misalignment	No requirement to date.	Head pulley alignment monitors.
Plugged spout	No requirement to date.	High-level indicators for vessels, which the elevator discharges to.

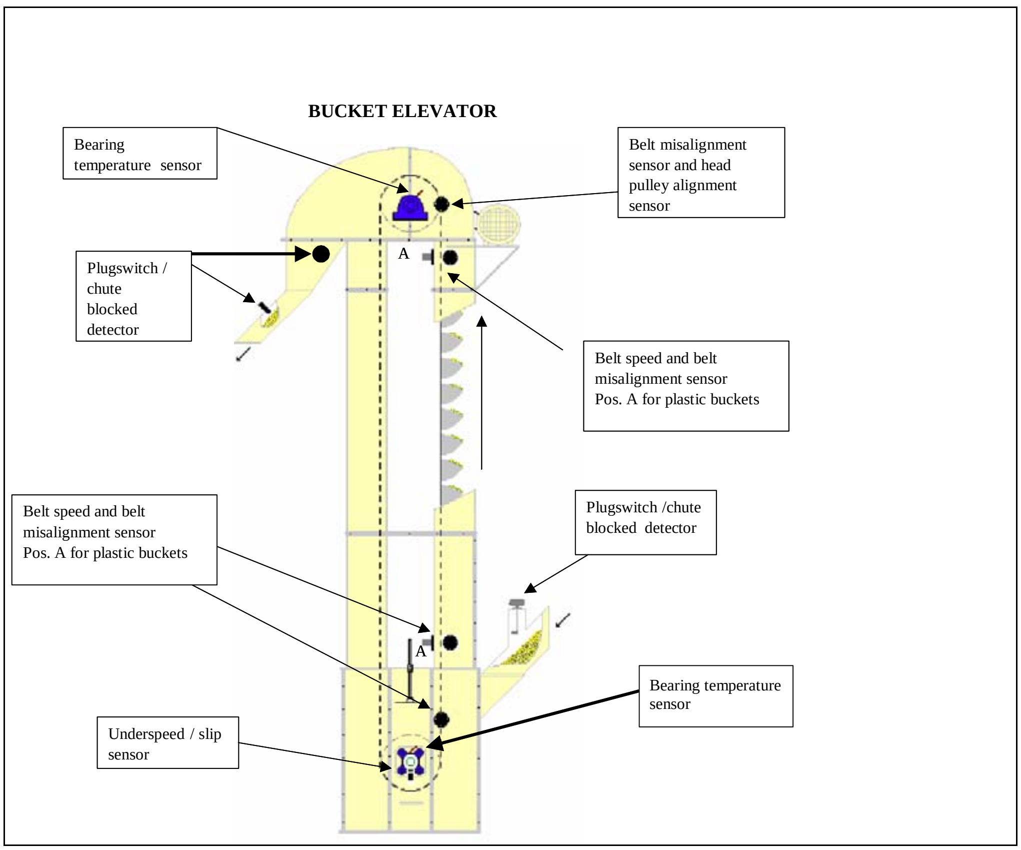


Figure 1. Bucket elevator sensor locations
Note: If the elevator has a bend (knee) pulley, those bearings should also be monitored. Installation of additional belt alignment sensors should also be considered at elevator idler pulleys.

Table 3.
Guide to NFPA requirements for monitoring devices on belt conveyors

Hazard	**NFPA Requirement (See NFPA 61 and NFPA 654 for full interpretation)**
Belt slip	Motion detection device to provide a shutdown at 20% reduction in normal belt speed and actuate an alarm.
Belt misalignment	No requirement to date however true alignment must be maintained to minimize friction.
Bearing failure	No requirement to date.
Pulley misalignment	No requirement to date however true alignment must be maintained to minimize friction.
Plugged spout	High-level indicators for vessels, which the conveyor discharges to.

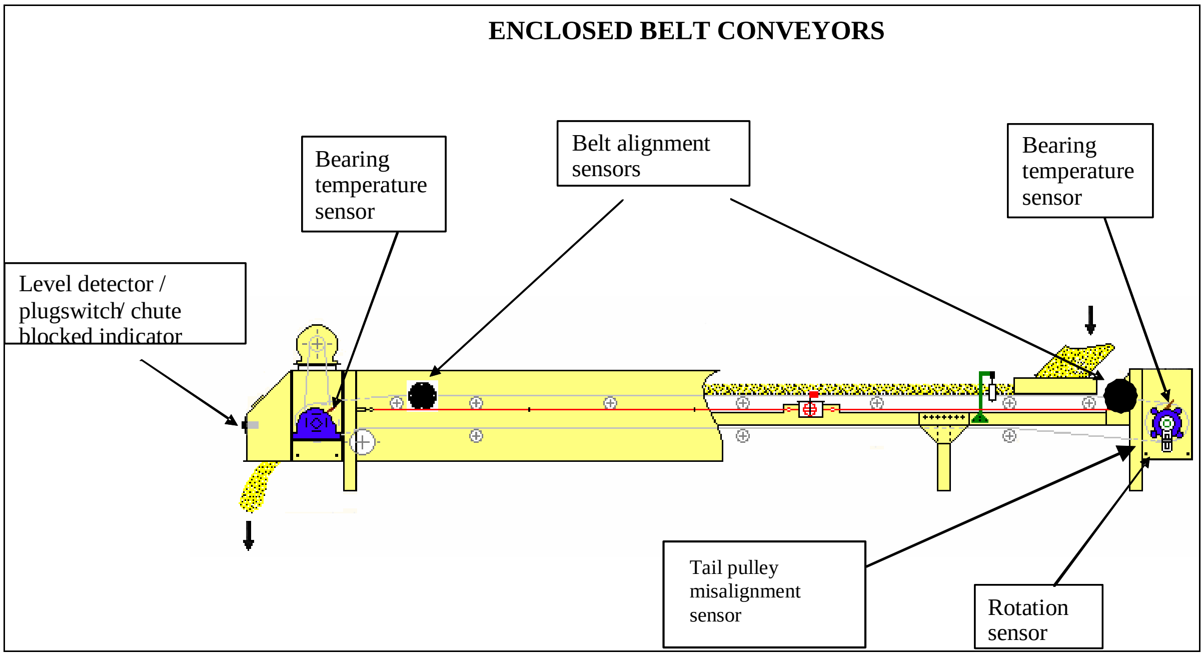


Figure 2. Enclosed belt conveyor sensor locations

Classes, Divisions, and Zones:
Once a decision has been made on which parameters are to be monitored then the monitoring equipment specification can be considered. The first consideration for this must be the suitability of the equipment for safe operation in and around the facility. Areas within and around a grain handling facility can be classified according to the US National Electrical Code (NEC). The areas concerning combustible dust, for example grain dust, are all Class II and can be found in NEC 500.5(C)(1) and (C)(2). The areas

concerning an explosive gas, such as hexane gas, are Class I. We are dealing primarily with the dust hazard in this paper, however serious consideration must be made for other hazards such as hexane gas, which is used quite extensively in certain grain handling processes. This gas is extremely explosive and because its vapor density is heavier than air it can accumulate in pockets and low areas such as reclaim conveyors and bucket elevator boot pits. Quite devastating explosions have occurred in plants where hexane has leaked from one plant to another and been ignited by a source in the receiving plant.

The dust hazard, Class II, areas are defined by divisions according to their potential danger with Division 1 being the highest risk, followed by Division 2. NFPA 654: *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids (2006)* provides guidance to determining area classifications. Table 4 summarizes this.

Table 4. Guide to NEC Class II Divisions

Division	Definition	Typical Area/Location
1	Hazard is present under normal operation	Inside the head or casing of a bucket elevator
2	Hazard is present only under abnormal conditions	Control room inside the plant

A further sub category defines the type of dust and divides it into three (3) groups **See table 5.**

Table 5. Guide to NEC Class II Groups

Group	Combustible Dust	Includes these materials
E	Metal	Aluminum, magnesium
F	Coal	Coal, carbon black, charcoal
G	Grain	Corn, flour, wood, plastics

All electrical equipment installed in and around a grain handling facility must be listed or approved for use in the specific classified area including the specific division and group.

Note:
1. Equipment must be approved for the specific Class of hazard and as such Class I (gas hazard) approved products are not approved for Class II (dust hazard).
2. Equipment approved for use in Division 1 areas can be used in Division 2 areas.

The products must be listed or approved by a third party testing laboratory such as Underwriters Laboratories (UL), Canadian Standards Authority (CSA), Factory Mutual (FM), Edison Testing Laboratory (ETL). Tests carried out by the laboratory are specific to the standard applied and one must be careful to use equipment approved to the applicable standards. A CSA approved sensor can be used in the US only if the sensor has passed the required US tests. This is usually denoted by the small US or NRTL

(Nationally Recognized Testing Laboratory) mark applied below the logo. The products are labeled with the appropriate listing mark and Company's name:

Example of an approved electrical equipment label for use in the USA and Canada:

LR# XYZ Manufacturer
CLASS II DIVISION 1 GROUP G.

European Approvals

In Europe all equipment must carry the CE mark before it can be sold or used. This mark is applied by the manufacture of the equipment and designates that all relevant European health and safety standards have been met. Before the CE mark can be applied to products intended for use in the dust hazard areas within the feed and grain industry the product must first be certified to the Atex Product Directive (94/9/EC). Atex is a contraction of "Atmosphere Explosible", the French term for "Potentially Explosive Atmosphere". Atex defines hazardous areas depending on the levels of risk similar to the NEC hazardous (classified) locations but there are three levels of hazard defined in Atex whereas NEC only defines two divisions. Table 6 provides a comparison guide.

Table 6. A comparison guide to Atex Zones and NEC Divisions

Atex Zone	Atex Definition	NEC Division
20	Dust Hazard continually present	1
21	Dust Hazard likely to be present	1
22	Dust Hazard not likely to be present	2

Note: The 2005 edition of the NEC was updated to include Article 506: *Zone 20, 21, and 22 Locations for Combustible Dusts, Fibers, and Flyings.*

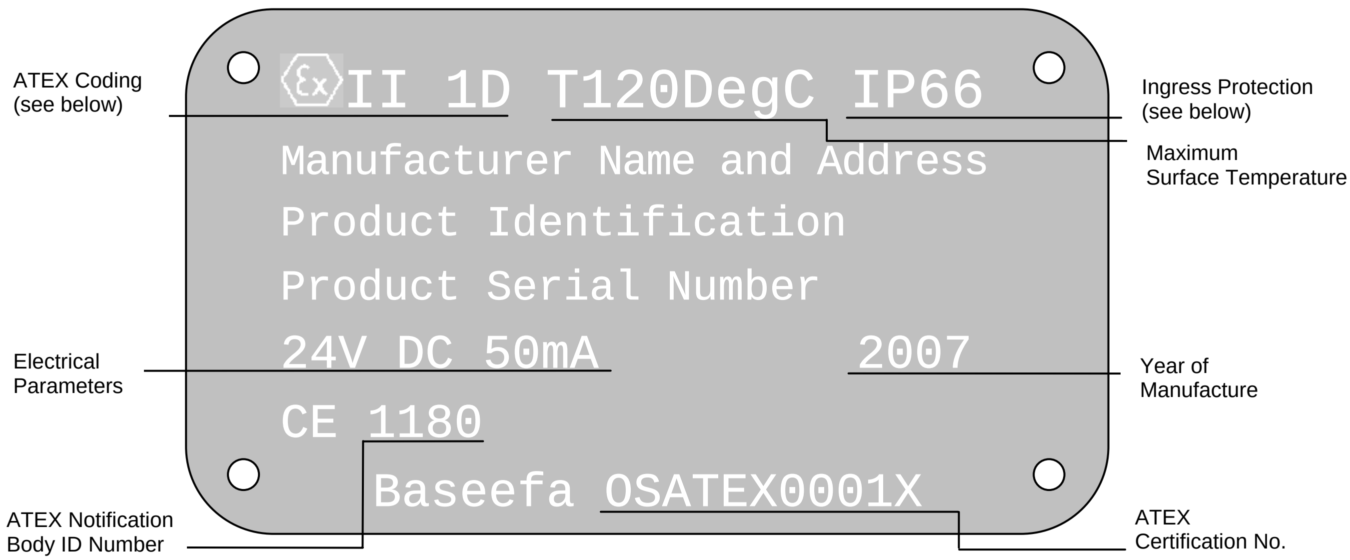


Figure 4. Example of approved product label for use in Europe

ATEX Coding
Ex II 1 D

Equipment Group: I for mining
II for non-mining
Equipment Category:
1 – very high protection – Zone 20
2 – high protection – Zone 21
3 – normal protection – Zone 22
D – Dust Hazard

Guide to Ingress Protection (IP)
DUST
IP 5x – Dust protected
IP 6x – Dust tight
WATER
Protected against:
IP x4 – splashing water
IP x5- water jets
IP x6 – powered water jets
IP x7 – temporary immersion
IP x8 – continuous immersion

Worldwide Approvals

Due to the many different standards and approvals for different countries the costs of obtaining and maintaining these approvals can be significant for the equipment manufacturer and ultimately for the equipment user. As such a global standard that is applicable across the world would prove a better solution. One such standard that is starting to gain acceptance in many countries is IECEx.

System Design

A hazard monitoring system consists of three basic elements: sensors, control device and alarm/shutdown signal. The sensors are mounted on the machine to detect the potential hazard and translate it into an electrical signal that is then transmitted to a control device. The control device then provides a signal to warn personnel and automatically shutdown equipment. A stand-alone control device dedicated to the hazard monitoring function designed specifically for use within the industry and for use with the specialized sensors is preferred. If required, this stand-alone system can be connected to the plant PLC system to provide visual/graphical indication to the plant operators at a central location and can also perform hazard logging and trending functions for plant maintenance personnel. With this type of system design the hazard monitoring function is not dependent upon the PLC and the system will continue to function quite safely and totally irrespective of what the PLC is doing. Occasionally the sensors are connected directly to the plant PLC without using a stand-alone control. This is not preferred as the PLC is not dedicated to the hazard monitoring function and actually performs many processing functions around the plant. However, the latest safety classified PLC's can be used to give added insurance but the programmer/software engineer must take responsibility for the program/code written to provide the safety function. (Three configuration diagram examples are shown in figure 5)

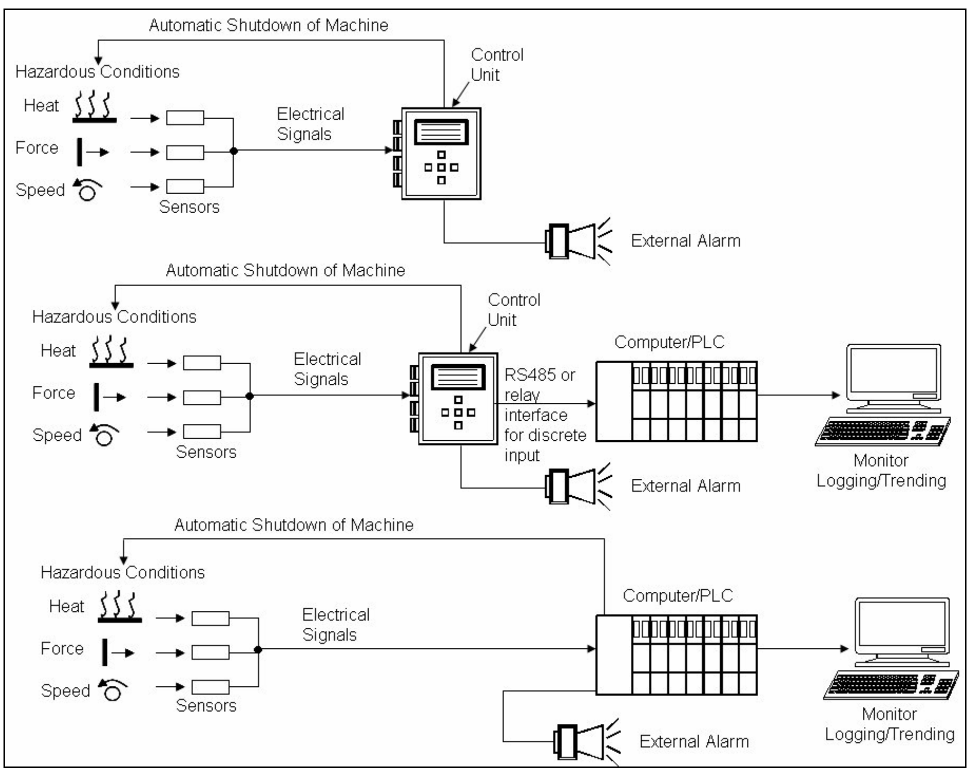


Figure 5. Typical configurations for hazard monitoring systems

Key features to look for in a Hazard monitoring control unit:
Hazardous area approvals (Class II Division 1 or 2, Group G)
Unique serial number identification
Well-documented instruction manual
Relay contacts normally energized for failsafe shutdown
Simple menu driven parameter set-up and adjustment
Visual display
RS485 serial communication output for PLC connection
In-built test and diagnostic functions

Figure 6.
Typical Multi-Hazard Monitoring System for belt speed, belt misalignment, bearing temperature, plug condition, and pulley alignment for belt conveyors and bucket elevators. (Photograph courtesy of 4B Components Ltd.)

System Sensors
The sensors are typically specialized for the feed and grain industry and standard industrial sensors are not normally used. The sensors need to be able to stand up to the extreme conditions found in the feed and grain industry and must also be safe to use within the potentially explosive dust atmosphere.

1. Belt Slip Sensors
Bucket elevators and belt conveyors consisting of two pulleys and a belt are capable of generating dangerous amounts of heat in the event of belt slip. Belt slip on the drive pulley can occur when the belt is loose or is overloaded. If a belt could be infinitely tight and capable of handling an infinite load then it would never slip, and the drive motor running at constant speed would eventually stall when the load surpassed its full load rating (as the load increases, 3-phase induction motors slow down only very marginally, they run at almost constant speed and when overloaded they stall). The motor load current during belt slip is typically less than the normal running load current and therefore contrary to common belief; current detectors or amp meters are not a good indication of belt slip. Slip must be detected by monitoring the speed of the belt directly from the belt (or bucket) or indirectly from the tail pulley rpm.

Because a 3-phase induction motor runs at constant speed independent of its load, a single sensor calibrated to the normal running speed can be used to detect belt slip. This sensor can be mounted in one of two locations on the bucket elevator. Either by the boot pulley to detect the rpm of a target attached to the shaft or on the casing to detect the speed of the passing buckets or bolts. Either location is suitable, although it is sometimes preferable to install sensors higher up on the casing to prevent possible damage from water and moisture in the boot area. When installing higher up on the casing, care must be taken not to be too far from the pulley. The further away from the pulley, the more the belt flaps and rolls and the more difficult it is for the sensor to detect the bucket bolts consistently. The types of sensors for both these locations are very different from each other and are not interchangeable. Because the target for the boot-mounted sensor is always uniform in its shape and its distance from the sensor, only a simple sensor with a short fixed range is required (figure 7). The sensor mounted on the casing however requires a much greater sensing range along with physical and electronic range adjustment so that it can be set-up correctly to cope with the normal side-to-side and front to back movement of the bucket bolts (Figure 9). When ferrous buckets are used instead of plastic buckets, the sensor mounted on the casing must be moved to detect the buckets instead of the bolts, in order to prevent false readings due to the sensor detecting the steel buckets through the belt (figure 8). It also important to understand that the upside, or tight belt side of the elevator has less belt movement and it is easier to set-up the sensor and provide a more constant speed signal on this side. On belt conveyors the sensor is normally mounted on the tail pulley, as there are no bucket bolts or steel buckets to detect.

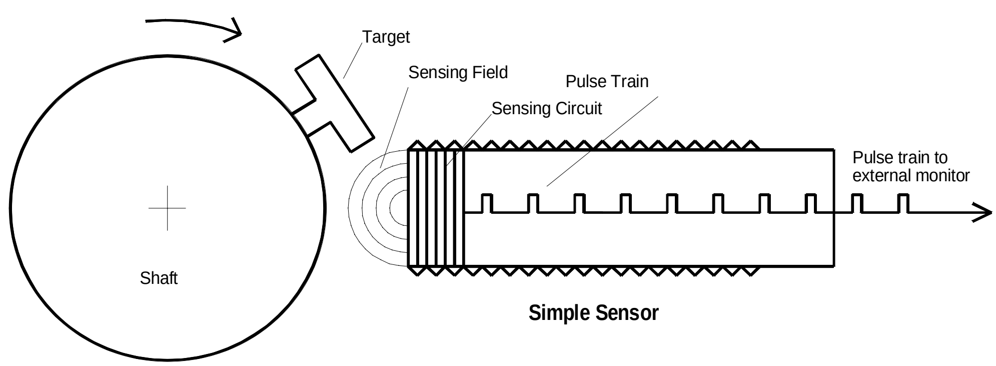
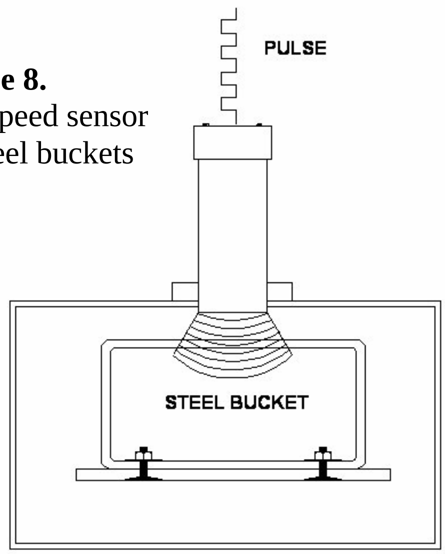


Figure 7. Simple shaft speed sensor

Figure 8.
Belt speed sensor
for steel buckets



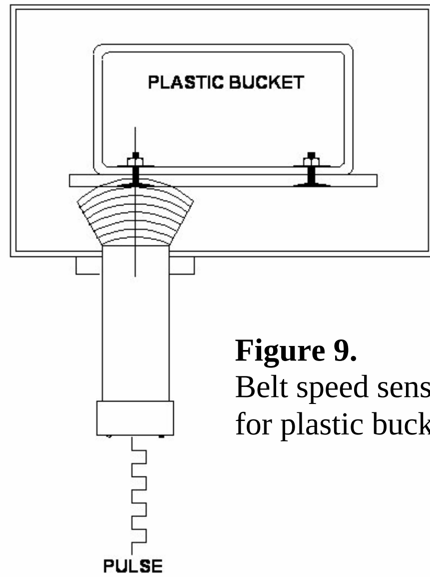


Figure 9.
Belt speed sensor
for plastic buckets

For monitoring the pulley shaft speed, the traditional system of standard inductive speed sensor with a fabricated mounting bracket, shaft mounted target and separate guard has caused some problems over the years with regard to speed sensing reliability. Also, since installations are rarely identical, there is usually a significant amount of site design and adjustment required to make the complete system function correctly and for this reason it was common to leave the details of the target, bracket and guard for the field personnel or the millwrights to figure out. Recent advances in this area have led to more reliable and standardized speed sensing installation by using a shaft-mounted sensor system. The sensor, the bracket and the guard are now available as one complete unit that is attached directly to the shaft and hangs on the shaft with no additional brackets required to hold the sensor. There is no on site fabrication or adjustment required and reliability is improved, as the sensor and target are integrally mounted. A typical shaft mounted sensor is shown in figure 10.

Figure 10. Typical shaft mounted speed sensor (photograph courtesy of Rolfes Co)

One of the other considerations when installing a speed sensor is the quantity of targets required on the shaft. The quantity of targets required depends on the shaft speed and the reaction time required. For example, a shaft running at 33 revolutions per minute (33 rpm) with 2 targets would produce 66 pulses per minute (66 ppm). If the underspeed alarm is set at 10% of normal running speed, then the alarm trip speed is 59.4 ppm. The minimum reaction time for a certain trip point is the time for the sensor to see the next pulse when running at the trip speed. Therefore at the 59.4 ppm alarm point the reaction time in seconds is 60/59.4, which is about 1-second. A 1-second reaction time is usually more than adequate for detecting underspeed on a belt conveyor or bucket elevator. If you used an encoder with 500 pulses per revolution, on the same shaft, the number of pulses per minute would be 16,500. This would give us a 10% underspeed alarm point of 14,850 ppm and a reaction time of 60/14,850 seconds (4 mS). Even if the control circuitry could count this fast, this reaction time is far quicker than what is required for a belt conveyor or bucket elevator and provides no additional benefit to its protection and just adds complication and cost. As we can see from table 7, if we require a reasonably quick alarm reaction time of around 1 second, only 4 targets are required for shafts running normally at 15 rpm or higher.

Table 7.
Reaction times for different shaft speeds and the number of targets required to achieve the reaction time

Shaft Speed (rpm)	**# of Targets**	**Reaction Time for 10% Underspeed**
30 to 60	2	1.1 to 0.56 seconds
15 to 30	4	1.1 to 0.56 seconds
6 to 15	10	1.1 to 0.44 seconds
3 to 6	20	1.1 to 0.56 seconds
1 to 3	60	1.1 to 0.37 seconds

Speed sensors for monitoring shaft speed are available in three standard formats: a simple sensor; an intelligent sensor; and a combination of both (see figure 11). The combined sensor provides both a signal for direct connection to an alarm/shutdown and a pulsed output for remote display of the speed on a control panel, PLC or tacho display. This option is usually preferred as it uses its own non-volatile software with output hardwired to the motor starter. The PLC or control has no effect over the shutdown function and only acts as a remote monitor or data logger. This arrangement usually provides a safer option and a very high level of confidence that the system will shutdown during a belt slip condition.

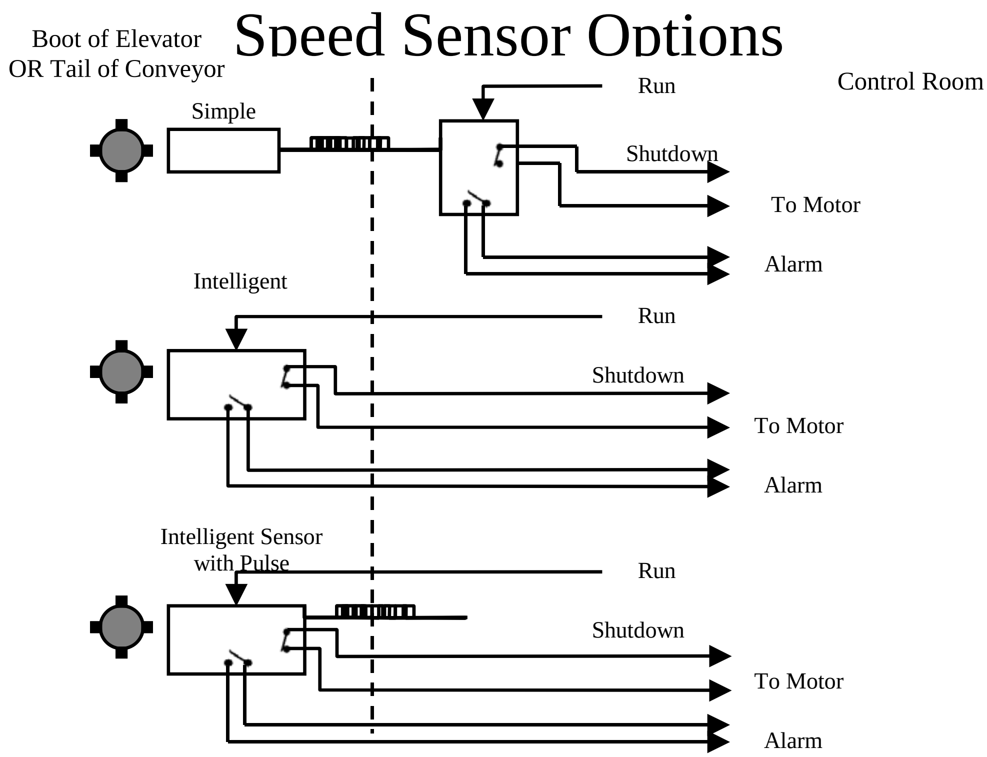


Figure 11. Three standard sensor formats for shaft speed monitoring (Simple, intelligent, and combined sensors)

Key features to look for in a shaft mounted speed sensor:
Hazardous area approval (Class II, Division 1, Group G)
Unique serial number identification
Relay contacts normally energized for failsafe shutdown
Conduit entry for connection of flexible sealtite
Status LED indication
Optional pulsed output for PLC input connection
Waterproof construction (IP 66 or better)
Sealed construction

Key features to look for in an elevator case mounted speed sensor:
Hazardous area approval (Class II, Division 1, Group G)
Unique serial number identification
Conduit entry for connection of flexible sealtite
Status LED indication
Sealed construction
Test function
Sensitivity adjustment

Adjustable mount

2. Belt Misalignment Sensors

Bucket elevators and enclosed belt conveyors have sidewalls, which a misaligned belt can rub against. Heat generated by this rubbing action can quickly reach a dangerous level, especially near pulleys where the belt side forces are usually the greatest. Figures 12 and 13 show severe belt misalignment on a bucket elevator. There are a number of different sensing technologies, available to detect a misaligned belt.

Figure 12. Inside elevator casing showing slit in steel casing due to severe belt misalignment

Figure 13. Outside elevator casing showing slit in steel casing and heat build-up due to severe belt misalignment

Limit Switches. Mounted on the side of the elevator casing these devices are activated when a belt moves over. Wear on the switch, due to belt friction, is kept to a minimum by using steel or ceramic rollers to activate the limit switch. However these types of switch are outdated and can be dangerous. With the belt running against the small roller, a typical roller speed of well over 1400 rpm can be generated. Serious problems can arise due to the bearings in the roller failing, resulting in dangerous heat generation. The mechanics of the switch can also wear out or become contaminated with material causing the switch to stick, since the switch mechanism must move a considerable amount to activate the contact. This type of system is not failsafe in any way. If a switch becomes loose and moves away from its mount, there is no way of realizing that the system is no longer monitoring.

Rub-Blocks. Placed on the side of the casing these devices incorporate a temperature sensor, which is similar to the sensors used in bearing temperature monitoring but usually with a lower trip point. Typical rub-block sensors have a trip point around 120 ° F. They are designed to detect the heat generated when the belt rubs against the brass or aluminum block. However these systems are out dated and can be dangerous. They require heat from friction of the rubbing belt to detect a belt misalignment, and their soft brass or aluminum face can wear very quickly. Sometimes a belt misaligns and rubs against the soft brass face for a short period of time and not long enough for the sensor to detect any significant heat build-up. Over time, these sporadic misalignments wear through the soft brass block and render it ineffective. Plant personnel are only aware that the sensor has been inactive after it has been removed for visual inspection during planned maintenance. Rub-blocks are also not failsafe. As with limit switch misalignment sensors, if they become dislodged from their mounting they will not indicate that there is any type of problem.

Optical Sensors. Using an Infra Red transmitter and a receiver to detect the belt misalignment. Sometimes a number of sensor / receiver pairs are used to provide a warning and then a shutdown as a belt misaligns. However, the set up on these types of systems can be tedious, as they tend to create false alarms due to sensor alignment problems and material/dust covering the sensor's lens. Sometimes air purging can help keep the lens clean but reliable operation is not assured in the dusty and rugged conditions found in the feed and grain industry.

Non-Contact Magnetic Sensor. One of the most common belt misalignment sensing devices for bucket elevators, these extended range proximity sensors are mounted on the elevator casing and detect the passing buckets or bucket bolts continuously. When the belt is tracking normally, each sensor produces a signal as the bucket or bolt passes through the sensing range. When the belt misaligns, one of the sensors begins to miss pulses and the control unit determines this as a belt misalignment. Since all belts misalign to some extent without contacting the side of the casing, the better systems use two sensors so that this normal belt wander does not cause false alarms. The sensors also have a range adjustment so that they can be "dialed in" to the normal running / wandering of the belt, and the control unit to which the sensors are connected, usually has parameter adjustments for accurate set-up. The active continual sensing of these devices provides the only real failsafe solution for belt misalignment detection on bucket elevators at this time.

Solid State Force Activated Switch. These devices can be used for belt misalignment detection on bucket elevators or belt conveyors. They measure the force applied to them by the belt as it touches their hardened stainless steel face. Even the smallest deflection can be detected immediately so that a control unit can be signaled and the belt can be stopped without delay. Since they need no heat build-up from belt friction to activate, they detect immediately and they can be useful in logging and trending belt misalignments for predictive maintenance purposes. These sensors can also be used to detect the edge of the pulley, if it misaligns. Unaffected by material or dust build-up, no site adjustment is ever required. Units are available with a built in test feature to ensure operation of the sensor and the control circuits, and an integral status lamp shows when the sensor is operated.

Misaligned Belts
Magnetic Sensors
For Bucket Elevators

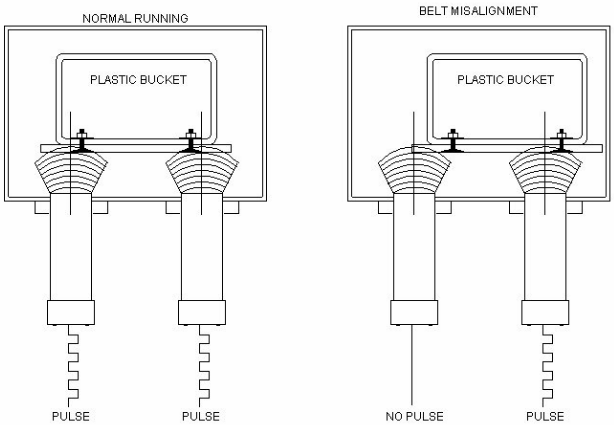


Figure 14. Non-contacting magnetic misalignment sensors detecting the steel bolts on plastic buckets in a bucket elevator

Figure 15. Force activated belt misalignment switch. (Photograph courtesy of 4B Components Ltd)

Figure 16. Force activated belt misalignment switches installed on enclosed belt conveyor

Belt Misalignment Technology Comparison Guide

	Initial Cost	"Fail-Safe"	Durability	Cost of Ownership	Applications
Force Switch	$$	✗	✓	$	Conveyors & Elevators
Rub-Block	$	✗ ✗	✗	$$$	Conveyors & Elevators
Limit Switch	$$$	✗	✓	$$	Suited to Open Conveyors
Magnetic Sensor	$$	✓	✓✓✓	$	ONLY Well Maintained Elevators

Figure 17. Belt misalignment comparison guide

Key features to look for in a contact style (force activated) belt misalignment switch:
Hazardous area approval (Class II, Division 1, Group G)
Unique serial number identification
Relay contacts normally energized for failsafe shutdown
Conduit entry for connection of flexible sealtite
Status LED indication
Sealed construction
Test function

Key features to look for in a non-contact magnetic style belt misalignment sensor:
Hazardous area approval (Class II, Division 1, Group G)
Unique serial number identification
Conduit entry for connection of flexible sealtite
Status LED indication
Sealed construction
Sensitivity adjustment

3. Bearing Temperature Sensors
All bearings create heat due to friction when running. When well maintained and lubricated this heat is minimal and well below the lower ignition temperature for the grain dust. However, if the bearing or lubricant fails in any way, rapid heat build-up can

occur and the bearing housing can reach a temperature high enough to ignite any dust accumulated on or around the bearing. Table 8 shows the ignition temperatures for various dusts.

Table 8. Guide to Ignition Temperatures for various dusts (source NEC)

Dust	**Layer or Cloud Ignition Temperature**
Wheat	220º C (428º F)
Rice	220º C (428º F)
Corn	250º C (482º F)
Wheat Flour	360º C (651º F)

All bearings on the machine should be considered a potential ignition source. Even outside bearings at the head of outside bucket elevators have caused serious explosions. The shaft can conduct heat into the head or the smoldering/burning grain dust on the bearing housing can be drawn into the head. All bearings will eventually fail and even the very best preventative maintenance programs won't catch all bearings before they begin to fail. The only safe approach is to install automatic bearing temperature monitoring systems, which monitor the bearing temperature continuously. These systems incorporate a bearing sensor mounted to the bearing housing and wired to an alarm control panel. Control relays within the panel provide warning and shutdown contacts when the bearing exceeds a user defined trip point.

CONVEYOR 27 BEARING
TEMPERATURE = 084º F
Amb 069º F : Relay 01
Rel 30: Abs 176: NTC

(Explanation)
This hazard monitor is measuring a bearing temperature of 84º F using an NTC sensor and the ambient temperature close to the location of the bearing is 69º F. If the bearing temperature was to reach 30º above ambient (i.e. 99º F) then the system will alarm and relay 1 (R1) would activate to shutdown the machine or warn the operators.

Figure 18. Continuous bearing temperature-monitoring system (Photograph courtesy of 4B Components Ltd)

Typical trip points for bearing temperature sensors are 176º F or lower.
However, more common nowadays are continuous bearing temperature sensors that can provide the operator with a visual readout of actual bearing temperature in real time on the control unit or monitor (See Figure 18)**.** These sensors and controls are able to provide relatively failsafe monitoring of bearings compared to the trip point sensors and are also able to provide bearing temperature logging and trending for preventative and predictive maintenance. Some systems can provide trip points relative to local ambient temperature and are therefore able to detect a bearing problem much earlier than a sensor with just an absolute trip temperature setting. Some systems also provide rate of rise of temperature monitoring and comparison between different bearing temperatures, all helping to provide an early indication of a problem.

Many systems are now utilizing some form of serial communication system allowing much reduced installation and maintenance costs. A single cable is used around the plant and connects to nodes with unique digital addresses. The nodes collect and transmit the temperature information along with local ambient temperature and sometimes belt misalignment information too. The network, or “Bus System” can then be connected to control devices for automatic alarm/shutdown or to the plant PLC.

Sensor manufacturers use a number of different technologies to convert the bearing temperature to a voltage or current signal, which can be read by a control unit.
These technologies include:

Thermistor sensors: these are thermally sensitive resistors and are available as Positive and Negative Temperature Coefficient versions (PTC and NTC respectively). The PTC sensor’s resistance increases exponentially as the temperature rises above a fixed trip point, and the NTC sensor’s resistance changes inversely to a temperature rise. PTC sensors are usually used to indicate when a certain temperature has been reached and can be called trip point sensors. They are a solid-state version of the old thermostat sensors. NTC thermistor sensors provide a proportional signal, which is used for continuous temperature sensing. Their reaction time is quick, they are very stable and they are ideally suited for the temperature ranges involved for bearing monitoring in the feed and grain industry. Also, large changes of resistance allow the monitoring system to easily differentiate open/short circuit conditions (see figure 20).

Thermocouple sensors use a junction of dissimilar metals, which produces a small voltage in proportion to the temperature sensed. The technology has been used for many years and is quite reliable and cheap, however special thermocouple wire and wiring techniques must be used since every connection becomes a potential thermal junction.

Thermocouples can be susceptible to electrical interference due to the very low signal levels that they operate at and the wires are a very small diameter (see figure 19) and must be adequately protected. It is also not possible to monitor for short circuit conditions (see figure 21) and any short in the thermocouple cables becomes a new thermal junction. There are however many plants in the feed and grain industry still using thermocouples with old multiplexing technologies. But as maintenance costs rise, plants are switching these old systems out to more modern and more versatile serial communication bearing temperature systems.

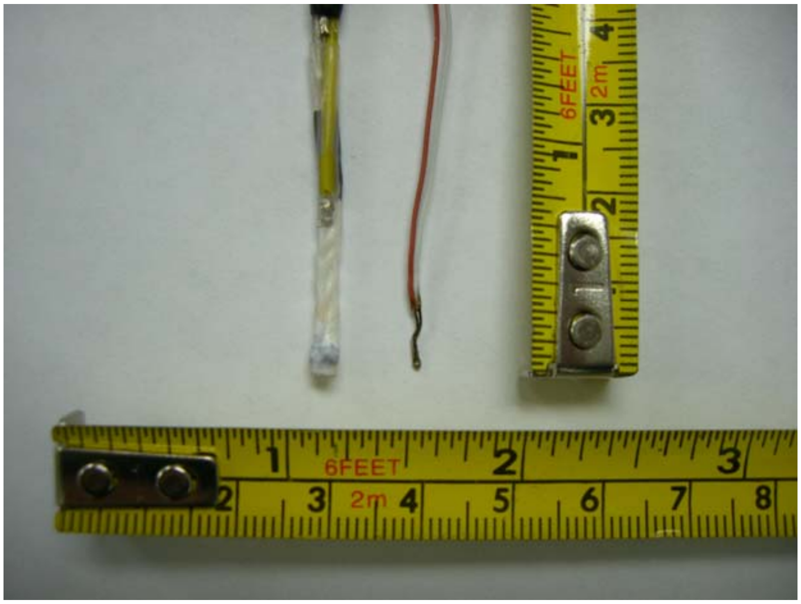


Figure 19. Photo of thermistor on left and thermocouple on right showing the bead size and the difference in cable diameters.

Resistance Temperature Detector (RTD): The most commonly used RTD has a Platinum element with a resistance of 100 ohms at 0ºC. The resistance increases linearly with temperature rise. 3 or 4-wire RTD’s are very accurate as they compensate for the resistance of the cable connecting the sensor to the control unit. These sensors are relatively expensive and although they are sometimes used in bearing temperature systems they are more geared towards more sophisticated process temperatures. Also, large changes of resistance allow the monitoring system to differentiate open/short circuit conditions.

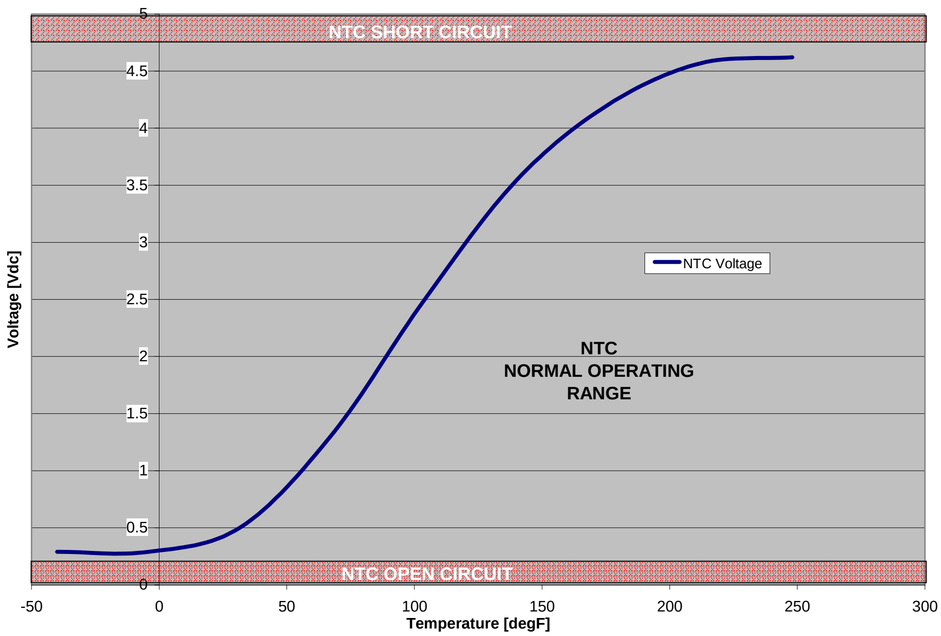


Figure 20. NTC Thermistor

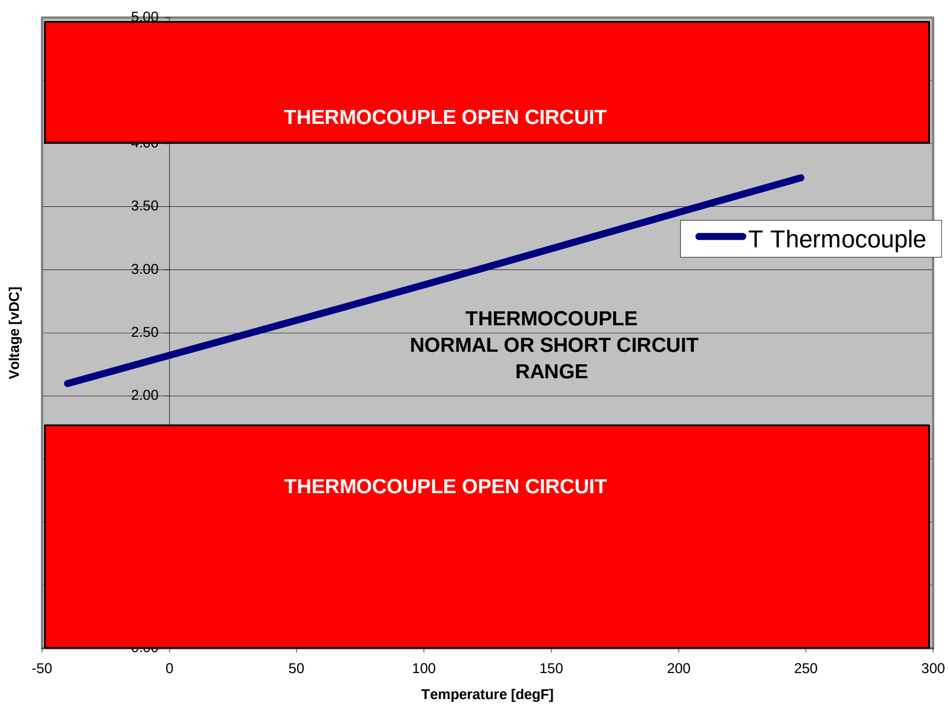


Figure 21. Thermocouple Sensor

Semiconductor Sensors: The latest development in temperature sensing uses silicon semiconductor technology. Usually manufactured as an integrated circuit (IC), these sensors are small, accurate, linear and low cost. As more and more facilities being built are using serial communication links instead of hard wire the digital sensor with individual address capability is becoming more popular. Instead of thousands of cables running through a plant, one main 4-wire communication cable is installed, with branches and nodes to individual machines. These sensors have a unique identification number, which can be addressed by a central computer or plant PLC. When addressed, temperature data is sent from the sensor along with the sensor ID number. The ID number and temperature is then displayed and used to alarm and shutdown the machine at a user defined trip point.

Some of the serial communication systems being designed today will accept the older RTD, Thermocouple or Thermistor technology by converting the signal to a digitally addressable data format. Thus enabling users to couple existing sensors to a data network, and also mix the old sensors with the new.

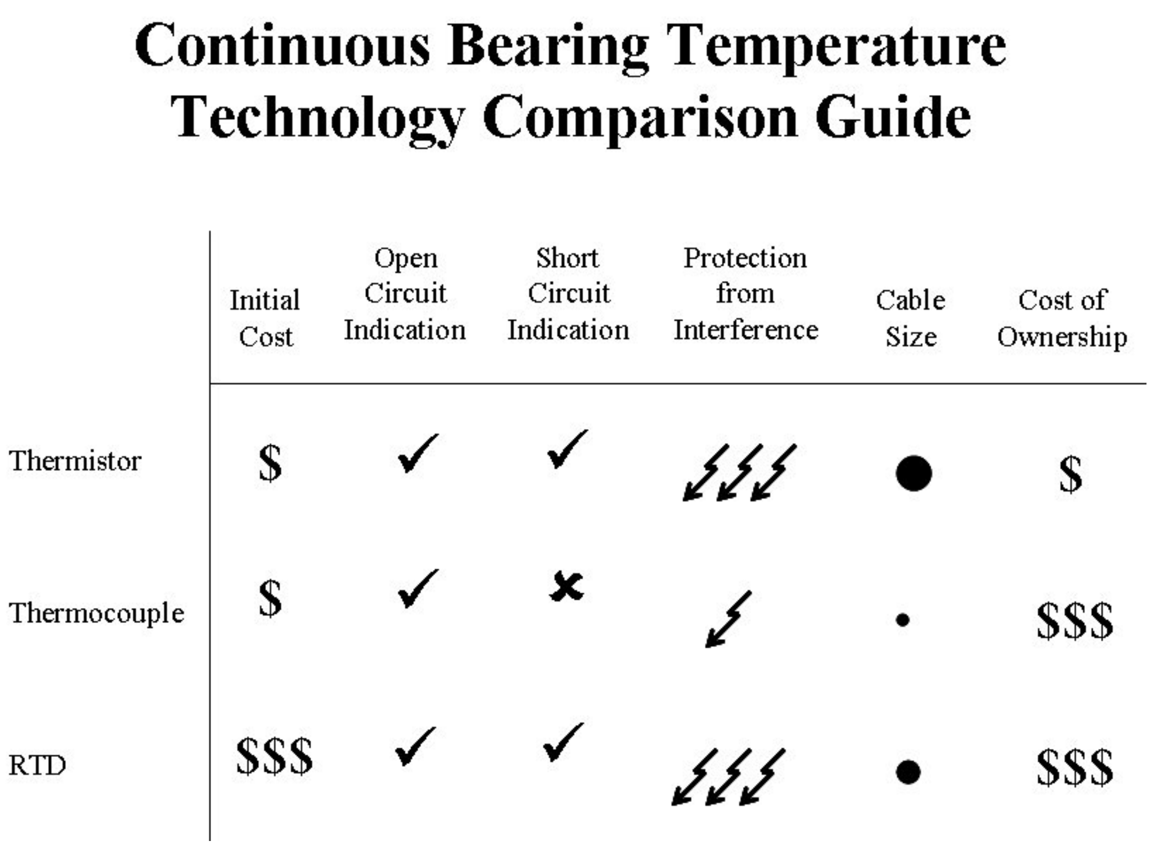


Figure 22. Continuous bearing temperature technology comparison guide

Key features to look for in a bearing temperature sensor:
Hazardous area approval (Class II, Division 1, Group G)
Unique serial number identification
Conduit Entry for connection of flexible sealtite
Robust construction
Positive mounting to the bearing (with grease through ability)
Open circuit detection (detects a wire break/disconnect)
Closed circuit detection (detects a wire short)
Visual temperature indication

Additional Sensors to consider for bucket elevators and belt conveyors

1. Head Pulley Misalignment Sensors:
The same sensors used for belt misalignment detection can usually be used for head pulley misalignment detection also. If the sensors are installed on the top half of the pulley, they will detect both belt and/or pulley misalignment. Sometimes non-contacting inductive style sensors are installed to detect the position of the steel pulley edge.

2. Plugged Spout Sensors:
It is recommended that sensors are installed in the discharge chute and are connected to shutdown the elevator or belt conveyor immediately upon a plug condition. When excessive delays are incorporated the boot of the elevator or drive end of the conveyor can quickly fill up with material, which can lead to belt slip, belt misalignment and other serious problems.

Mount the plug sensors as close to the discharge as possible but outside the normal material flow. Be careful not to impede material flow with the sensor. Consider mounting additional plug sensor on the downside of the leg near the boot. If using rotary style indicators, use only units that are failsafe in their design.

3. Tail pulley misalignment sensors:
On many enclosed conveyors, the tail pulley incorporates a belt re-loading mechanism that runs very close to the casing. Any pulley misalignment can cause the pulley to rub against the casing and create significant amounts of heat. The two common methods of detecting this involve an inductive sensor mounted on each side of the pulley or lug/plate style continuous temperature sensors mounted to the outside of the casing.

Equipment Selection Summary:
There are many manufacturers of hazard monitoring equipment. Be careful to choose a well-respected reputable company that specializes in equipment for the feed and grain industry. Also check that the manufacturer is able to provide after sales service and technical support, along with help in product selection and installation advice. Remember, hazard monitoring equipment should be designed to provide many years of

service so it is important to be confident that the original equipment supplier will be available to help with system support should it ever be needed in the future.

Most approved equipment should have a unique serial number that allows it to be traced throughout the manufacturing process to the sale of the product and installation. All equipment should be provided with a detailed installation and operation manual that should be available for the customer to view prior to purchase.

Whenever possible choose equipment that allows for fail-safe installation and offers a high degree of confidence. In general, only equipment that is designed to automatically shutdown the machinery when a hazardous condition is detected or when any sensor fails or wire breaks can claim to be failsafe. An alarm horn or alarm lamp is not failsafe and should only be used as an early warning. As such, always install a failsafe shutdown mechanism in addition to any alarm or warning device.

The installation of the hazard monitor should not affect the way your plant functions with regard to equipment interlocking. If you already have a system that automatically stops any equipment feeding the monitored machine (i.e. all upstream equipment) then the installation of a hazard monitoring system with automatic shutdown should have no effect on the way this operates.

Installation

General:
Choose a professional electrical installer who is familiar and has experience with installing hazard-monitoring equipment within the feed and grain industry. Many good electricians are not experienced with installing these types of sensors and controls. There are challenges specific to our industry, including potentially explosive atmospheres in which the installer has to work safely and in which the equipment has to be installed correctly following all applicable laws and regulations, confined entry hazards and moving machinery hazards.

On new plants, make sure that hazard monitor installation is planned well in advance. Too often it is left to the last minute and there is a lot of pressure on the electricians and a big rush to get the installation complete. When purchasing the elevator or conveyor discuss the hazard monitors with the manufacturer so that pre-installation can be accomplished in the shop. Most equipment manufacturers already offer optional hazard monitoring equipment and their machines have been designed to accommodate the mounting of the sensors allowing easy and simple on site installation.

On existing plant, give the elevator or conveyor an overhaul prior to installation of sensors making sure that belts are not slipping under load, belts are not misaligning and bearings are running within normal temperatures. Take readings and make note of the normal operating conditions including shaft speeds and bearing temperatures. Paint over any old rub or burn marks on casings prior to installing belt alignment sensors.

When installing an alarm device, consider the location carefully. Audible alarms must be loud enough to be heard over the background plant noise and since plant operators may be wearing hearing protection it is advisable to install a flashing beacon lamp in addition to the audible alarm. Consider special alarm signaling devices such as an automatic pager or GSM device.

Mechanical:

Locate monitors in a suitable control room close to operators. Mount the units at eye level so that operators can readily read the display. Do not locate them inside control panels where they cannot be seen. Do not locate them outside in direct sunlight as elevated temperatures can degrade some displays.

Install belt misalignment sensors for enclosed belt conveyors on the topside of the belt and inline or very close to the pulley. Make sure that when the belt misaligns it will contact the sensor and not ride over it. When installed on the return (underneath) side, hardened grain can cause the belt to ride above the sensor.

If installing rub-blocks, it is sometimes a good idea to install on a hinged door since access will be required frequently to inspect the sensor face.

To help prevent mechanical damage and protect from rodents, install sensor wiring inside rigid metal conduit and where flexibility is required use short liquid tight flexible conduit or sealtite with fittings approved for the area.

One of the common problems with conduit systems is the ingress of water. Many electricians understand that no matter how well a conduit system is installed, at some stage a cover could be left loose or condensation can accumulate. This moisture can be channeled to sensors and over time can accumulate and eventually damage the wires or sensor. As such, low conduit drains, approved for the location (see figure 24) should be installed and sensor wiring should be “Teed” with an adequate wiring loop so that water following the wires is not channeled to the sensor. Part of the regular system maintenance should include the cleaning of any accumulated debris from around the conduit drains and the inspection of conduit systems for water ingress. Figure 23 shows hazard monitors installed on the boot of an outside bucket elevator. Belt alignment, shaft speed, and bearing temperature sensors are installed using flexible sealtite with adequate loops and the steel conduit is installed with low point drains.

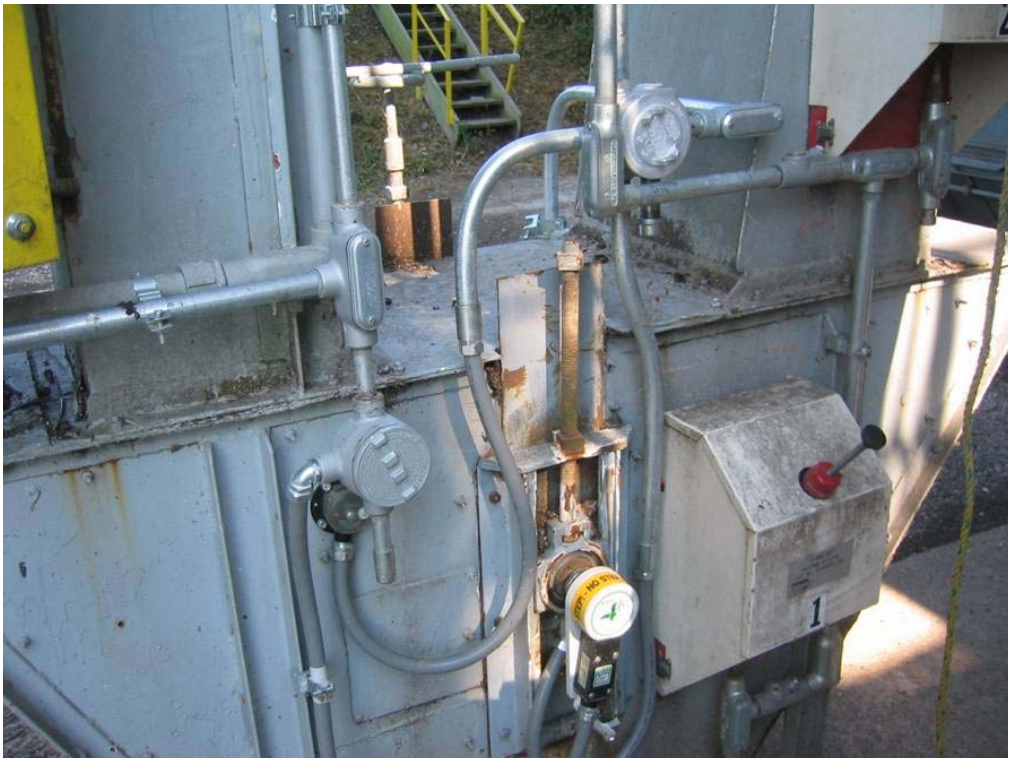


Figure 23. The boot of a bucket elevator showing the hazard monitoring sensors installed and low point conduit drains on the conduit system.

Figure 24. Approved conduit drain on left and general propose drain on right.

Network and computer wiring:
Special attention should be paid to the installation of systems with communication cables and systems with low voltage wiring. Shielded cables should have only one connection to ground (usually at the control unit) and an open circuit ohm reading would verify this when the shield is removed from the ground connection and the meter is placed between the shield and ground.

Small stranded wires connected to terminals should be installed using a booted ferrule system (see figure 25) to ensure the mechanical connection of the wire to the terminal and to contain the strands. When connecting sensor cables using wire “lugs” make sure that the correct size is used.

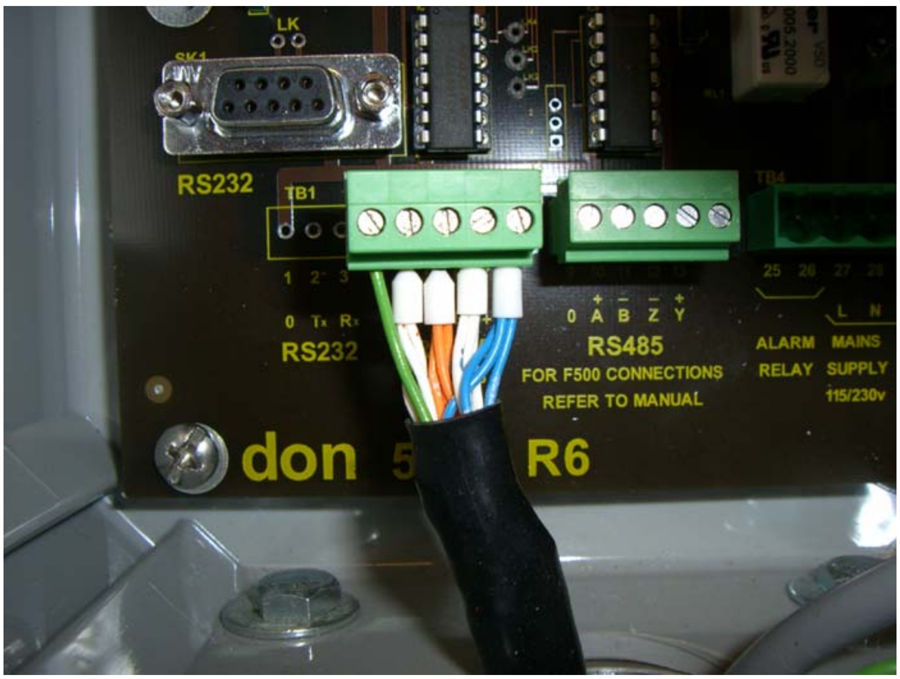


Figure 25. Photograph of network wires connected to terminals with a booted ferrule wiring system.

Special attention should be made to the shield wire in shielded cables. A braided shield made up of many fine conductors should be carefully handled so that there is no chance of them touching the other conductors and causing a short to ground. Insulated the shield wire using a wire sheath (which can be the outer PVC jacket pulled from standard copper cable). When the cable includes a drain wire, cut back the shield, insulate the drain wire and use it as the shield connection. The shield should be one continuous connection through the system and should be connected to ground at one point only. This one ground connection should be made at the end of the cable, and is normally done at the control unit end.

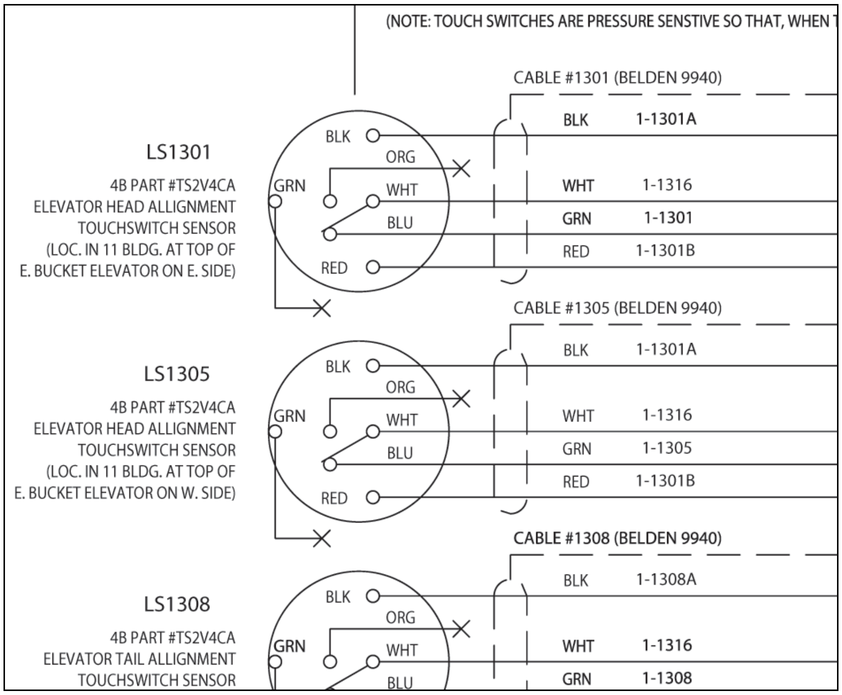


Figure 26. Customers wiring diagram detail
(Partial schematic shown)

Network and computer wiring should be segregated from higher voltage wiring for safety and functionality.

Some sensors and systems use Intrinsically Safe (IS) wiring which must be installed carefully and following NEC Article 504. All Intrinsically safe wiring must be physically and electrically separated from nonintrinsically safe wiring and special grounding techniques apply.

Equipment instruction manuals normally include installation-wiring schematics. However these are general and not specific to the facility where the equipment is being installed. The Electrical installer should produce a professional set of wiring schematics specific to the installation, which should include wire numbers, equipment labels, and other specific information (see figure 26).

When planning the wiring runs keep to a standard color system. If your plant does not already have a standard system, then decide on one. Try to maintain the same wiring color through connections and terminals. Use wire numbers on the wiring schematics and on the physical wires. The example in figure 26 shows part of a customer’s wiring schematic. The wires have wire numbers, colors are noted, the location of the sensor is noted, and the sensor has been given a unique identification number and description. The type of field cable being used is noted. The manufacturer’s part number is noted.

Do not use larger than required signal cables. Larger cables take up more room, are more expensive, and are more difficult to connect into small terminals.

PLC ladder logic diagrams and Input/Output data sheets should be included where applicable, along with back-ups on CD's or hard drives.
Never run the machine without an active hazard monitoring system. A number of spare sensors and components should be kept at hand so that plant down time is kept to a minimum.
During installation, the plant manager should periodically inspect the wiring and conduit installation, making sure that the connections are neat and tidy and a high level of quality is being maintained (figure 27 shows a poor wiring install, figure 28 a good wiring install). Ideally the installer should test for continuity as each section is completed. Whenever possible the installers should remain on the same job from start to finish. Whenever multiple crews are involved the standard of installation can suffer and the time taken to complete the job can be longer.

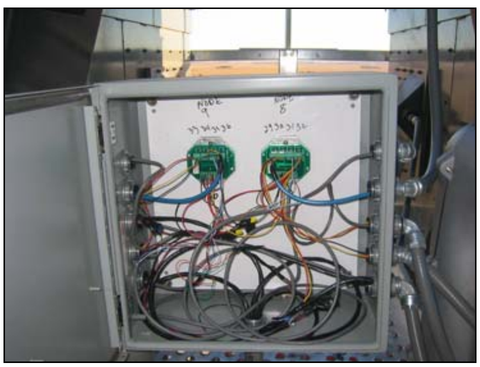


Figure 27. Poor wiring installation

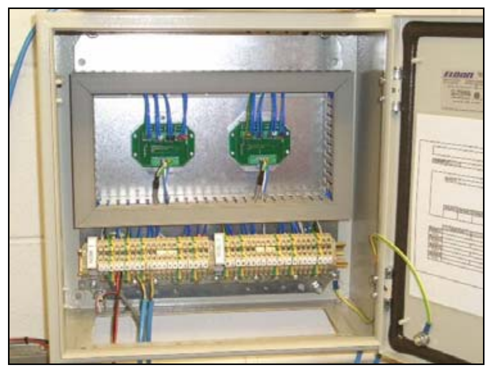


Figure 28. Good wiring installation

Speed Sensor Installation

When installing speed sensors to monitor shaft speed, use either a shaft-mounted sensor as described earlier or install an inductive speed sensor using a universal sensor mount (figure 29).

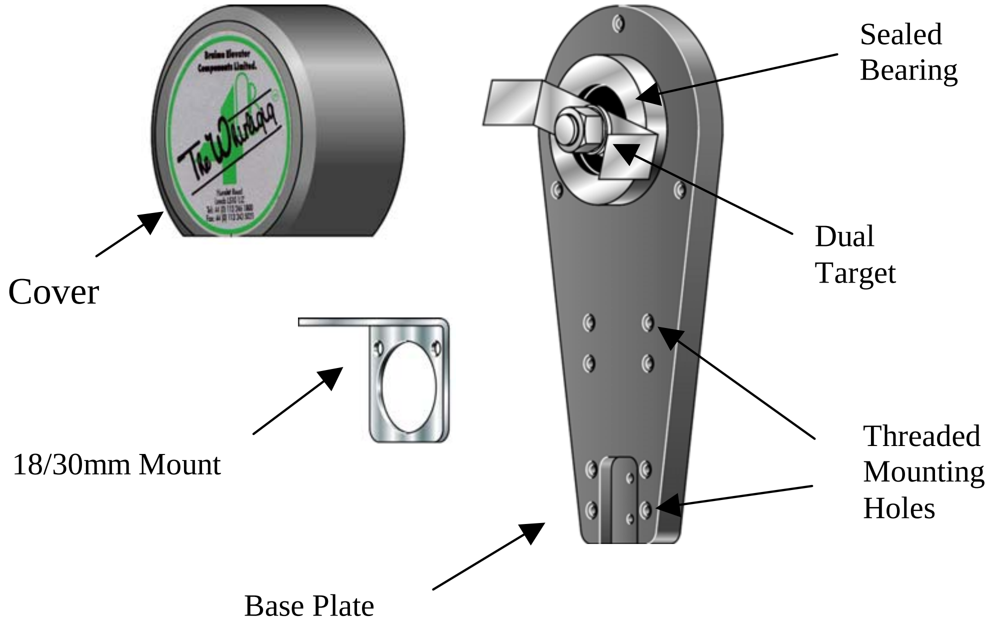


Figure 29. Universal shaft sensor mount

This type of speed monitoring system is much easier to install, much safer, and more reliable. Since many machines require periodic belt tensioning that involves moving the monitored shaft, a traditional speed sensing installation requires careful consideration for the attachment of the bracket, which holds the sensor to the machine. The bracket must be able to move with the shaft as the belt is tensioned so that the target on the shaft remains within the sensors sensing range. By design the shaft mounted sensor installation requires no such consideration as the whole assembly is attached to the machines shaft, and therefore moves with it. Also, machine vibration can sometimes cause problems with a traditional shaft speed sensing system for the same reason. The typical sensing range for the inductive sensor is 7/16". If there is a clearance of ¼" between the rotating target and the face of the sensor then the absolute maximum tolerance is 3/16". Under heavy loads and machine vibration the clearance between target and sensor could exceed 3/16", resulting in periodic false alarms or nuisance shutdowns. When a shaft mounted sensor installation is used, the sensor and target are mounted on the same plate, so that the distance from the target to the sensor remains the same no matter how severe the vibration is.

Since the sensor, the target, the bracket and the guard are all one assembly that hangs from the machine's shaft only a single hole drilled in the end of the machine's shaft is required for installation. Some systems are also available with a magnetic attachment so that no drilling or threading of the shaft is required.

Testing and system handover:
One of the most important parts of the installation will be the final system test. Good installers should have a full understanding of how the system works and will have tested the system passively as the installation progresses. When it comes time to run the system a good electrician will be confident that the system will work as expected, but will nevertheless perform a full and thorough test of the system in the presence of the plant manager and other key personnel.

This test must be done in a safe manner, and without the introduction of conveyed or elevated material.

Ideally, real life conditions should be forced so that the correct operation of the equipment, wiring, and auxiliary equipment can be confirmed.

Upstream equipment should always be interlocked with downstream equipment so that automatic shutdown will not result in a plug condition.

After successful testing, the installation is complete and the system should be handed over. A final walk through by the plant manager and the installers will ensure that the manager has a full understanding of the sensors and controls which have been installed

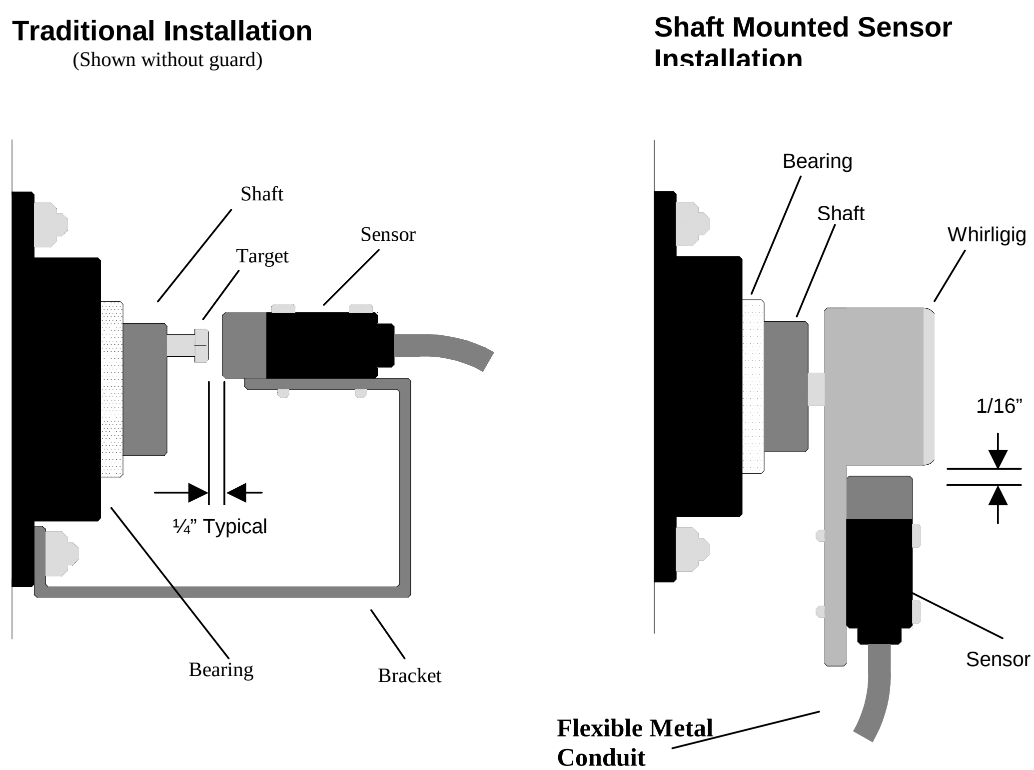


Figure 30. Speed sensor mount.
Traditional vs. Shaft Mount

and the capability of the system. The manager will also ensure that the work areas have been cleaned and no debris has been left. During this handover there should be allowance for training of operators and key personnel. Instruction manuals, installation schematics, spare parts, emergency contact numbers and any outstanding issues should all be addressed.

Maintenance

Even a solid state electronic monitoring system with failsafe design requires periodic maintenance to ensure that you will have trouble free monitoring and so that you can be confident that the system will perform when required. Some of the maintenance checks you can easily perform include:

Follow manufacturers test procedures and record results. Remove from service any machine that shows a problem, until the monitoring system is up and running again.

Physical inspection of the sensors and controls can provide invaluable information as to the status of the system. A sensor could have come loose from its mount and may need attention. Bearing sensors or belt misalignment sensors do no good when hanging in mid air! Rub sensors can be rubbed through and only visual inspection can catch this.

Repair any damaged conduits or wiring connections found. Replace missing junction box lids.

On a regular basis inspect contact style belt misalignment sensors for wear or damage. Physical checks of contact sensors should be made periodically, the frequency depending on the application and the amount and duration of detection.

Check bearing temperatures using a hand held IR temperature sensor and compare this with what the system is indicating.

Check pulley speeds and compare to initial system start-up values. If no values were recorded then make sure the belt is tight and not slipping, and compare unloaded and loaded rpm. There should be negligible reduction in speed when fully loaded.

Where practical, compare resistance values of temperature sensor circuits to known start-up values.

The hand held devices in figures 31, 32, 33, 34 are essential tools for hazard monitoring maintenance, inspection and testing. However, be sure to use either approved equipment or only when the dust hazard is not present.

Figure 31. Hand held tachometer

Figure 32. Hand held temperature indicator

Figure 33. Digital multi-meter

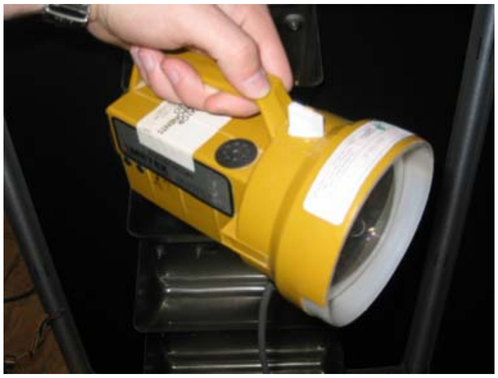


Figure 34. Hand held stroboscope

Summary

The safe operation of plant and machinery within the grain and feed industry requires a conscientious effort from plant designers, machine manufacturers, installers, plant managers, operators, and maintenance personnel. The threat of a catastrophic event is always present and a well designed, professionally installed, and well maintained hazard monitoring system will help to make the plant safer and more productive.

References:

1. NFPA 49: *Hazardous Chemicals Data (2001)*

2. NFPA 61: *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities (2002)*

3. NFPA 69: *Standard on Explosion Prevention Systems*

4. NFPA 70: *National Electrical Code (2005)*

5. NFPA 499: *Recommended Practice for the Classification of Combustible Dusts and Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas*

6. NFPA 654: *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids (2006)*

7. NMAB 353-4: *Classifications of Dusts Relative to Electrical Equipment in Class II Hazardous Locations, published in 1982 by the Committee on Evaluation of Industrial Hazards, National Materials Advisory Board, Commission on Engineering and Technical Systems, National Research Council, and National Academy of Sciences.*

8. OSHA Title 29: *Code of Federal Regulations,* Part 1910.272.

9. *National Fire Codes Vol. II. The Prevention of Dust Explosions (1946) – NFPA*

10. *KSU – Dust Explosion Report (March 20, 2006) – Robert Schoeff*

11. *Dust Explosions in the Processing Industries (1999)- Rolf K Eckhoff*

