MASTER THESIS

Sensorics for Mining and Conveying Equipment

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Laser Collision Protection System for Bulk Handlings Machinery

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SANDVIK MINING AND CONSTRUCTION

Declaration

I declare in lieu of oath, that I wrote this thesis and performed the associated research my self, using only literature cited in this volume.

Leoben, Mai 2008 *Mohammad Valian*

Abstract

The main task of this work was the protection against collision between the boom and the stock pile, as well as other equipment, in open pit mining. A further task was the exact representation of the functionality of all the sensors used for the machines working in open pit mining as well as in underground mining. Three specific sensor technologies were available for collision protection, namely the principles of ultrasonic, microwave and laser. After studying the advantages and disadvantages of these three sensor types and after carrying out several trials of a laser measuring system, it was found that the laser sensor was the most suitable. Although this is not appropriate for any and every case, it could still be shown that it has important advantages compared to other devices. The measurement characteristics of the laser measurement sensors were determined using various conditions of operations. In this way it was possible, in the scope of this work, to make a clear recommendation for the use of such an LMS system for the future applications of the company Sandvik.

Kurzfassung

Die Hauptaufgabe dieser Arbeit war der Kollisionsschutz zwischen Auslegern und der aufgebauten Halde als auch anderen Geräten und Maschinen in Tagebau. Eine weitere Aufgabenstellung war die genaue Darstellung der Funktionsweisen aller für die Maschinen verwendeten Sensoren im Tage- und Untertagebau. Für den Kollisionsschutz standen drei spezifische Sensortechnologien zur Auswahl, nämlich die Prinzipien Ultraschall, Mikrowellen und Laser. Nach dem Studium von Vor- und Nachteilen dieser drei Sensorentypen und Durchführung von mehreren Versuchen an einem Lasermesssystem stellte sich der Lasersensor als geeignetster heraus. Obwohl diese nicht für alle erdenkliche Einsatzfälle geeignet ist, zeigt er doch wesentlich Vorteile gegenüber den anderen Geräten.

Die Messcharakteristik des Laser Measurement Sensors wurde unter verschiedenen Betriebszuständen bestimmt. Dadurch konnte im Rahmen dieser Arbeit eine eindeutige Empfehlung für ein solches LMS an die zukünftige Anwenderfirma Sandvik gegeben wurde.

بسم الله الرحمن الرحیم

تقدیم به پدر و مادر عزیزم که همواره مشوق و حامی بنده در امر تحصیل بوده و با دنیایی از عشق چراغ ایمان را در دل من روشن نگه داشتند.

دوستدار شما   محمد

ABBREVIATIONS AND ACRONYMS

MCS	**M**ission **C**ontrol **S**ystem Supervisory system controlling and monitoring the autonomous operations including traffic management and provides the remote operator’s user interface.
ACS	**A**ccess **C**ontrol **S**ystem For isolating the autonomous operating area to ensure safety of personnel.
PLC	**P**rogrammable **L**ogic **C**ontroller
VPS	**V**ideo **P**rogram **S**ystem
E-HOUSE	**E**lectrical Switch room
LCS	**L**ocal **C**ontrol **S**tation
CCR	**C**entral **C**ontrol **R**oom
RCC	**R**adio **C**ontrol **C**onsole, which is the radio harness control station.
V V V F	**V**ariable **V**oltage, **V**ariable **F**requency
A/D	**A**nalog to **D**igital
D/A	**D**igital to **A**nalog
AC	**A**lternating **C**urrent
HF	**H**igh **F**requency
IC	**I**ntegrated **C**ircuit
UV	**U**ltra**v**iolet
LVDT	**L**inear **V**ariable **D**ifferential **T**ransformer
RTD	**R**esistance **T**emperature **D**etector
LMS	**L**aser **M**easurements **System**
LASER	**L**ight **A**mplification by **S**timulated **E**mission of **R**adiation
RADAR	**Ra**dio **D**etecting **a**nd **R**anging
LED	**L**ight **E**mitting **D**iode

CONTENTS

APPENDIX

1. Introduction

Bulk materials handling is an engineering field that is centred around the design of equipment used for the transportation of materials such as ores and cereals in loose bulk form. Bulks materials handling systems are typically comprised of moveable items of machinery such as conveyor belts, stackers, reclaimers, ship- loaders / unloaders, various shuttles, hoppers and diverters, combined with storage facilities such as stockyards, storage silos or stockpiles. The purpose of a bulk materials handling facility is generally to transport material from one of several locations (i.e. a source) to an ultimate destination. Providing storage and inventory control and possibly material blending is usually part of a bulk materials handling system.

These systems can be found on mine sites, ports (for loading or unloading of cereals, ores and minerals) and processing facilities (such as iron and steel, coal-fired power stations, refineries).

Mine automation promises several benefits, mainly improved working conditions and safety, increased production, reduced maintenance costs, as well as optimized trimming speeds and smoother equipment operation. These are all possible with the help of different kinds of sensors or captures which are used nowadays.

1.1. Motivation and Objectives

The first task of this thesis is to make a useful documentation of the combination of sensors which are used in the following areas, to give an overview to the technicians and engineers using the equipment and further to make it possible to have a comparison between the functionality of sensors used in the open pit - and underground mining machinery.

The main goal of this thesis is to analyze and compare different possibilities and solutions for collision protection between the boom and the stock pile in the bulk handlings machinery (stacker / reclaimer) as well as problem treatment for bucket wheel slip monitoring.

The solution shall be fulfilled with taking the following points into account:

- The machines work in a dusty environment (dust rises from the stock piles)
- The influence of light on sensors (The machines work around the clock)
- The influence of vibration on sensors (Vibration caused by the length of the boom)

The stacking or reclaiming of the bulk material at or from the stock yards will be carried out with the help of a 40 to 60 meter long boom. As the stock pile grows the boom luffs up. The boom is not allowed to come in contact with the stock pile during its luffing or slewing motion.

1.2. Structure of the work

The thesis is organized as follows:

Chapter 2 gives a theoretical background of some physical principles for better understanding of the principles of sensors.

In chapter 3 sensor principles, their applications and the functionality of the sensors are discussed.

Chapter 4 provides a comprehensive study of measurement principles.

Chapter 5 focuses on the sensors used in continuous mining and tunnelling machines. For that purpose a road header and an AVSA have been analyzed.

Conveyor systems have been also discussed separately in chapter 6 with regard to sensors and automation.

Chapter 7 focuses on the sensors used in bulk handlings machinery. A stacker and a reclaimer have been analyzed for this purpose.

Chapters 5 and 7 begin with a description of the machines and their functions, to give a better understanding of the purpose the sensors serve.

Finally chapter 8 discusses the problem treatments mentioned above.

The numbers, values and content used in this work (for chapters 5 and 7) are from the sandvik company and they differ most of the time from machine to machine.

2. THEORY

2.1 General

For understanding the principle of sensors, their functionality and applications, it is important to have a basic knowledge in physical and electrical principles. Therefore in chapter three some sensor definitions like as calibration, accuracy, etc. will be described. Chapter four defines some measurement principles like as temperature, pressure, and flow measurements.

2.2 Physical Fundamentals

2.2.1 Wave

Periodic waves (Figure 2-1) consist of patterns that are produced over and over again by the source. The following definitions help to get a better overview about these phenomena.

- Cycle: A wave is a series of many cycles.
- Amplitude *A*: The maximum distance between a highest point on the wave pattern and the undisturbed position.
- Wavelength λ: The wavelength is the horizontal distance between any two successive equivalent points on the wave.
- Period T: The period is the time required for the wave to travel a distance of one wavelength. In other words it is the time required for one complete up/down cycle.
- Frequency f: The frequency of a wave is the number of cycles per second.

$$f = \frac{1}{T} \tag{2.1}$$

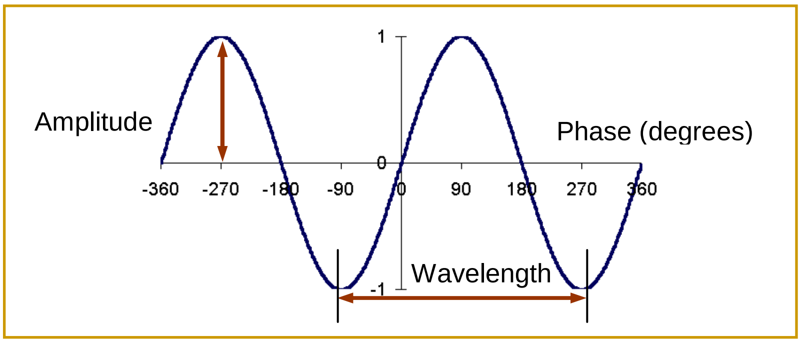


Figure 2-1: Periodic Wave.

2.2.2 Electric Charge and Electric Force

2.2.2.1 Electric Charge

The electric charge is a property of positive and negative charges, protons (+) and electrons (-). Experiment shows that the magnitude of the charge on the proton exactly equals the magnitude of the charge on the electron. The SI unit for measuring the magnitude of an electric charge is the Coulomb (C). One coulomb is the amount of electric charge transported by a current of one ampere in one second. It can be defined as one farad of capacitance times one volt of electric potential difference.

2.2.2.2 The Electric Force

It is a fundamental characteristic of electric charges that like charges repel and unlike charges attract each other. The Electric force acting on a point charge q_1 as a result of presence of a second charge q_2 is given by Coulomb's law.

$$F = k\frac{q_1.q_2}{r^2} \tag{2.2}$$

where, k is a constant and r is the distance between the two charges.

2.2.3 Capacitor and Capacitance

A capacitor stores electric charge and consists of two conductors placed near one another without touching and the region between the conductors or plates are filled with an electrically insulating material called a dielectric. Each plate carries a charge of a same magnitude, one positive and the other negative. Because of the charges the electric potential of the positive plate exceeds that of the negative plate by an amount voltage V.
The magnitude q of the charge on each plate of a capacitor, as shown in equation 2.2, is directly proportional to the magnitude V of the potential difference between the plates.

$$q = CV \tag{2.3}$$

Where, C is the capacitance with the SI unit of coulomb/volt = farad (F)
One farad is an enormous capacitance. Usually smaller amounts, such as a microfarad (1µF= 10^{-6} F) or a picofarad (1pF= 10^{-12} F) are used in electric circuits.

Substance	Vacuum	Air	Teflon	Paper	Water
Dielectric constant *k*	1	1.00054	2.1	3.3	80.4

Table 2-1: Dielectric constant for some common substances.

$$k = \frac{E_0}{E} \tag{2.4}$$

E_0: Field magnitude without the dielectric

E: Field magnitude inside the dielectric

2.2.4 Ohm's Law

The ratio $\frac{V}{I}$ is a constant, where V is the voltage applied across a piece of material (such as a wire) and I is the current passing through the material. In the following equation R is the resistance of the material. The SI unit of resistance is Volt x Ampere (*V.A*) or ohm Ω.

$$\frac{V}{I} = R \text{ = constant or } V = IR \tag{2.5}$$

2.2.5 Electric Power

When there is a current in a circuit as a result of a voltage V, the electric power P delivered to the circuit is as the following equation which is measured in watts.

$$P = IV \rightarrow \quad P = I(IR) = I^2R \rightarrow \quad P = (\frac{V}{R})V = \frac{V^2}{R} \tag{2.6}$$

2.2.6 Magnetic Fields

The magnetic field is a vector and its magnitude B is defined as:

$$B = \frac{F}{q_0}(v \sin\theta) \tag{2.7}$$

where, F is the magnitude of the magnetic force on a positive test charge q_0 and v is the velocity of the charge and makes an angle (0 ≤ θ ≤ 180°) with the direction of the magnetic field.

SI Unit of magnetic field: $\frac{\text{newton} \cdot \text{second}}{\text{coulomb} \cdot \text{meter}} = 1 tesla\ (T)$ (2.8)

1 gauss= 10^{-4} tesla

2.2.7 Pressure

The pressure p is the magnitude F of the force acting perpendicular to a surface divided by the area A over which the force acts.

$$p = \frac{F}{A} \quad (2.9)$$

SI unit of pressure: $\frac{N}{m^2} = Pascal\,(pa)$

A pressure of 1 pa is a very small amount. Many common situations involve pressures of approximately 10^5 pa, referred to one bar of pressure. Alternatively , force can be measured in pounds and area in square inches, so another unit for pressure is pounds per square inch (lb/in^2), often abbreviated as “psi”.

2.2.8 Light

Light is an electromagnetic radiation with a wavelength between 4.0 X 10^{14} Hz (red light) and 7.9 X 10^{14} (violet light). The wavelength is relationship between the velocity of light and the frequency of light. The frequency of visible light is referred to as colour (Figure 2-2). “The visible light has boarders with ultraviolet rays and infrared rays [1]”. Light not only vibrates at different frequencies, it also travels at different speeds. The equation 2.10 shows the relationship between the frequency, the speed and the length of a light wave.

$$\lambda = \tfrac{c}{f} \approx \frac{300000000\ m/s}{f} \quad (2.10)$$

λ ... wavelength; c …wave speed; f …wave frequency

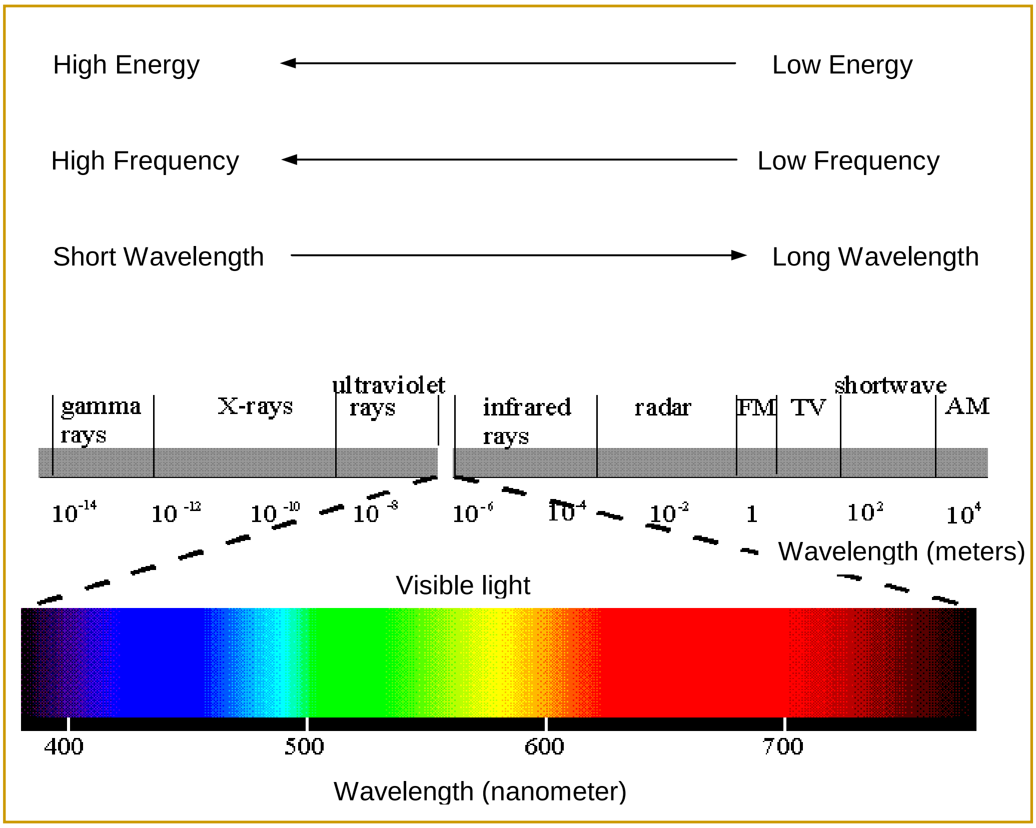
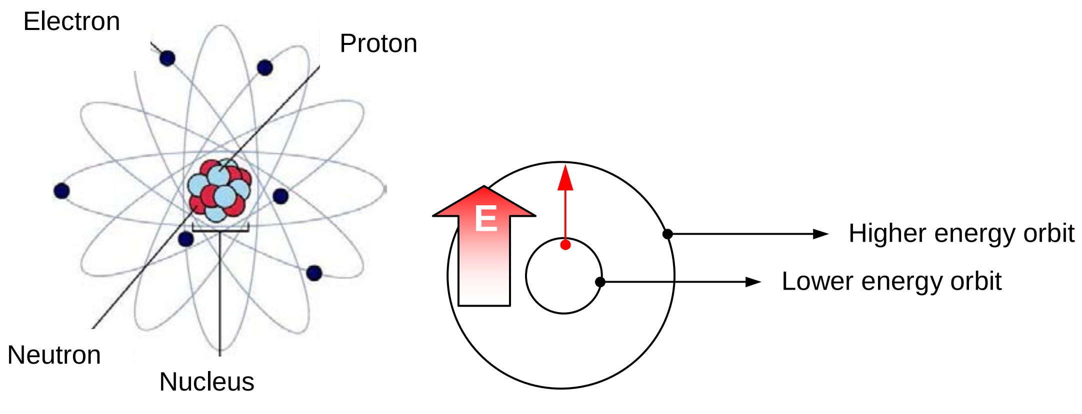


Figure 2-2: Electromagnetic Spectrum.

Einstein considered the photoelectric effect, in which ultraviolet light hits a surface and causes electrons to be emitted from the surface.

2.2.9 LASER

For better understanding of laser principle and its functionality, it is useful to have a look at the structure of atoms. Atoms are constantly in motion, move and rotate continuously (Figure 2-3). Atoms can be in different energy states. The level of this energy depends on the amount of energy that is applied to the atom via electricity, light or heat.



a) Structure of atom b) Electron displacement between the orbits

Figure 2-3: Structure of Atom.

As shown in the above figure, Atoms with different orbits have different energy levels. Also with heating an Atom, some of the electrons in the lower-energy orbits would transit to higher energy orbits.

This is actually the main idea of how atoms work in terms of lasers. Once an electron moves to a higher orbit, it eventually wants to return to the ground state and so it releases its energy in form of a photon (a particle of light).

laser (**l**ight **a**mplification by **s**timulated **e**mission of **r**adiation) is a device that controls the way that energized atoms release photons.

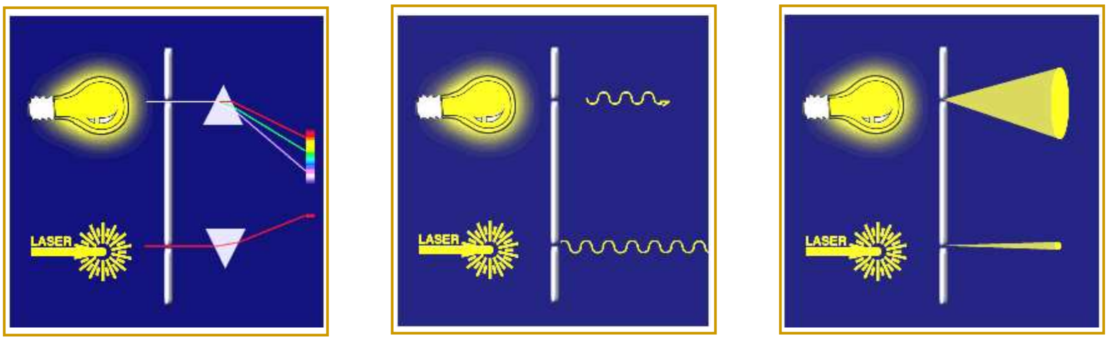
2.2.9.1 Laser Light

Laser light distinguish itself by its following characteristics:

1. Monochromatic: They only produce radiation of a specific wavelength — i.e. of a specific color (Figure 2-4 a).

2. Coherence: “The wave-trains emitted by a laser are much longer than those from an incandescent lamp. Some lasers have a coherence length of up to 107 m and this characteristic of laser beam is used in measuring techniques [2]” (Figure 2-4 b).

3. Intensity, emittance and brilliance: A laser light has a very tight beam and is very strong and concentrated. A flashlight, on the other hand, releases a very weak and diffuse light in many directions (Figure 2-4 c).



a) b) c)

Figure 2-4: Laser light characteristics.

2.2.9.2 Stimulated Emission

The tree important properties of laser can be take place by a process called stimulated emission (Figure 2-5). In opposite to spontaneous emission, in stimulated emission, the emission of photon is organized. This process can occur only if a photon encounters another atom that has an electron in the same excited state. In this case the emitted photon from the second atom vibrates with the same frequency and directions the incoming photon. Some ways to make these organized emissions (pumping) are: energy source, resonator, plan mirrors (with different reflectivity R) or reinforcing medium.

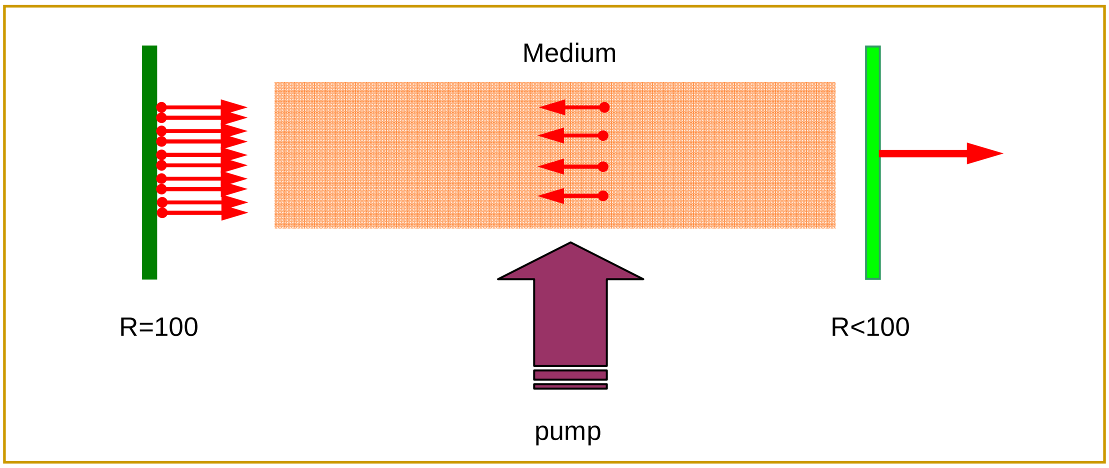


Figure 2-5: Laser function principle.

2.2.9.3 Laser classification

Lasers are classified into four major areas depending on the potential for causing biological damage. The laser type, which is used in this work are under the first class category.

Class I: Lasers or laser systems incapable of producing damaging radiation during intended use are Class I lasers. These lasers are exempt from any controls or administrative requirements during normal use.

Class I. A: This is a special designation that applies only to lasers that are "not intended for viewing," such as a laser scanner.

Class II: Class II lasers (low power) are lasers emitting radiation in the visible portion of the spectrum. Even though the power of these lasers is such that they will normally be protected by a physiological aversion response (blink reflex), personnel should wear laser eyewear for protection. The class II maximum permissible exposure limits can be exceeded if the beam is viewed directly for extended periods.

Class III: These are intermediate-power lasers, which are hazardous only for intra beam viewing. Most pen-like pointing lasers are in this class.

Class IV: These high power laser systems produce radiation that may be dangerous to the eye even when viewing a diffuse reflection. The direct beam can produce skin damage and can also be a fire hazard.

2.2.9.4 Laser applications in the industry

The laser light has lots of applications in the industry because of its magnificent characteristics named above. Some of these applications are as follow:

- Thickness measuring of rolling-mill products
- Centring purposes (tunnelling)
- Wheel alignment
- Automation (welding, cutting and measuring of metals)
- Quality control
- Process monitoring
- Medicine
- Special machinery

2.2.10 Heat and Temperature

An object with a high temperature is said to be hot, and the word “hot” brings the word “heat” to the mind. Heat is energy that flows from a higher-temperature object to a lower temperature object because of the difference in temperatures. Popular temperature scales are Celsius, Fahrenheit and Kelvin. The following equations will be used to converting from one unit to another:

$$(°F) = 1.8 * (°C) + 32$$
$$(°C) = (K) - 273.15 \qquad (2.11)$$

Absolute zero point means that temperatures lower than -273.15℃ cannot be reached by continually cooling a gas or any other substance.

2.2.11 Electromagnetic Induction

The Figure 2-6 illustrates one of the ways a magnetic field can be used to generate an electric current. It shows a bar magnet and a coil of wire to which an ammeter is connected. When there is no relative motion between the magnet and the coil, the ammeter reads zero, means no current exists. However, a current appears when the magnet moves toward the coil and also when the magnet moves away from the coil (with a reverse direction). Now the field at the coil becomes weaker as the magnet moves away, and once again it is the changing field that generates the current. Only relative motion (it doesn't matter which one moves) between the magnet and the coil is needed to generate a current.
The current in the coil is called an induced current because it is induced by a changing magnetic field. Since a source of emf (electromotive force) is always needed to produce a current, the coil itself behaves as if it were a source of emf. This emf is known as an induced emf. Thus, a changing magnetic field induces an emf in the coil, and the emf leads to an induced current.

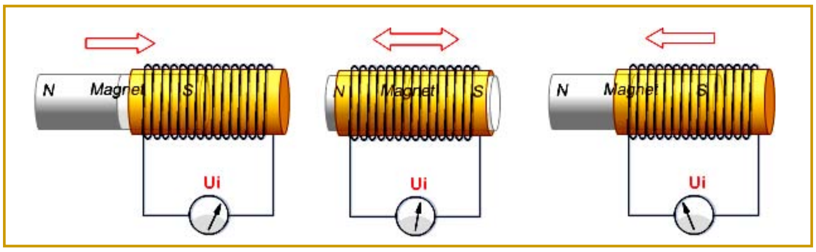


Figure 2-6: Electromagnetic Induction.

2.2.12 Self - Induction

The effect in which a changing current in a circuit induces an emf in the same circuit is referred to as self-Induction. The magnetic field here is not an external source such as a permanent magnet or an electromagnet. An electromotive force (emf) can be induced in a current-carrying coil by a change in the magnetic field that the current itself produces. The alternating current (Figure 2-7) creates an alternating magnetic field that, in turn, creates a changing flux through the coil. The change in flux induces an emf in the coil, in accord with faraday's law.

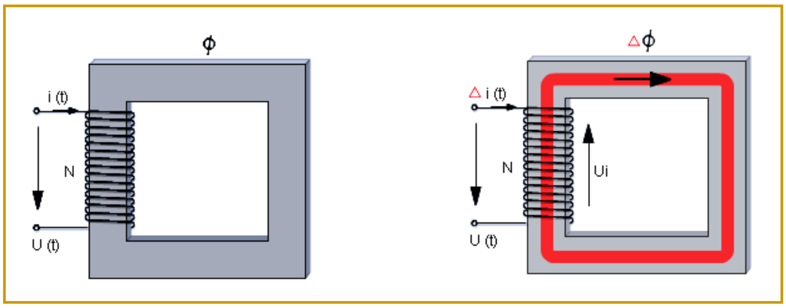


Figure 2-7: Self-Induction Principle.

2.2.13 Electromagnetic Waves

In general, any electrical charge that is accelerating emits an electromagnetic wave, as shown in Figure 2-8, whether the charge is inside a wire or not and it can travel through a vacuum or a material substance. In an alternating current, an electron oscillates in simple harmonic motion along the length of the wire and is one example of an accelerating charge. An electromagnetic wave, like any other periodic wave, has a frequency *f* and a wavelength *λ* that are related to the speed *v* of the wave by the following equation:

$$v = f\lambda \tag{2.12}$$

Electromagnetic waves exist with an enormous range of frequencies, from values less than 10^4 Hz to greater than 10^{22} Hz. Light is for example an electromagnetic wave.

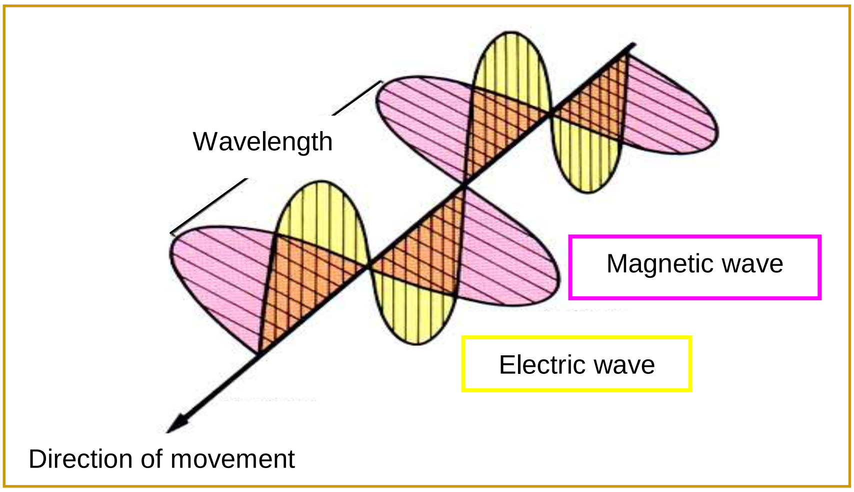


Figure 2-8: Electromagnetic Wave.

3. SENSORICS FUNDAMENTALS

A measurement assigns a specific value to a physical variable. A measurement system is a tool used for quantificating the physical variables. A general scheme for a measurement system is illustrated in Figure 3-1.

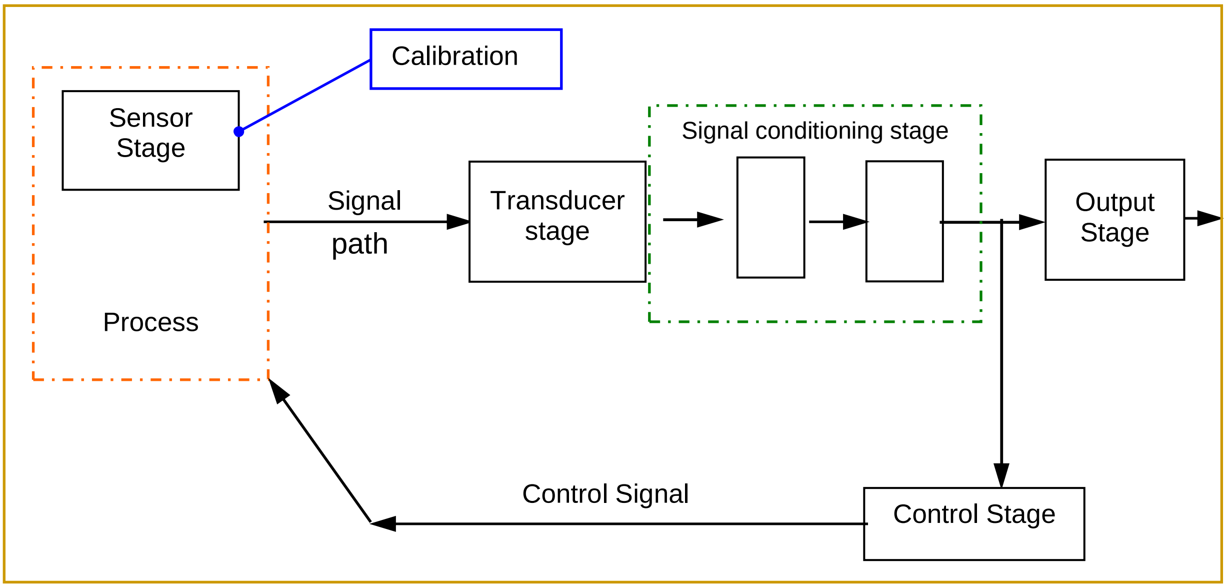


Figure 3-1: General structure for a measurement system.

The relationship between the input information, as acquired by the sensor and the system output is established by a calibration.

The sensor is a physical element that uses some natural phenomenon to sense the variable being measured, and the transducer converts this sensed information into a detectable signal form. The goal is to convert the sensed information to a form that can be easily quantified.

Signal conditioning stage modifies the transducer signal to a desired form. “This optional intermediate stage might be used to perform tasks such as increasing the magnitude of the signal through amplification, removing portions of the signal through some filtering technique, and/or providing mechanical or optical linkage between the transducer and the output stage, for example converting a translational displacement of a sensor into a rotational displacement of a pointer.” [3]

The output stage indicates the value of the measurement. The output equipment might be a simple readout display or it might contain devices that can record the signal for further analyses. The feedback-control system contains a controller that interprets the measured signal and makes a decision regarding the control of the process.

3.1 Calibration

The act of applying a known value of input to a measurement system for the purpose of observing the system output is called calibration. The known value used for the calibration is called the standard. Static - and dynamic are two common types of calibrations.

3.1.1 Static Calibration

The static calibration is the most common type of a calibration, which refers to a calibration procedure in which the values of the variables involved remain constant and they do not change with time. In this procedure, a known value is input to the system under calibration and the system output is recorded. In static calibrations, only the magnitude of the known input and the measured output are important.

3.1.2 Dynamic Calibration

We need dynamic information when the variables of interest are time dependent. In a broad sense, dynamic variables are time dependent in both their amplitude and frequency content.

3.2 Range

Known inputs ranging from the minimum to the maximum values for which the measurement system is to be used. These limits define the operating range of the system. The input span r_i and the output span r_o (full-scale operating range FSO), are expressed in the following equations:

$$r_i = x_{\max} - x_{\min} \tag{3.1}$$

$$r_o = y_{\max} - y_{\min} \tag{3.2}$$

3.3 Accuracy

The accuracy of a system can be estimated during calibration and it refers to the ability of a measurement system to indicate a true value exactly and it is related to absolute error. If the input value of calibration is known exactly, then it can be called the true value.

$\varepsilon =$ True value – Indicated value

from which the percent accuracy is found by:

$$A = (1 - \frac{|\varepsilon|}{true \quad value}) \times 100 \qquad (3.3)$$

Accuracy, as shown in the equation, can be determined only when the true value is known.

3.4 Hysteresis

Hysteresis error refers to differences in the values found between going upscale and downscale in a sequential test as shown in Diagram 3-1. Hysteresis is usually specified for a measurement system in terms of the maximum hysteresis error found in the calibration, eh_{max}, as a percentage of a full-scale output range.

1) A sequential test applies a sequential variation in the input value over the desired input range. This may be accomplished by increasing or decreasing the input value over the full input range.

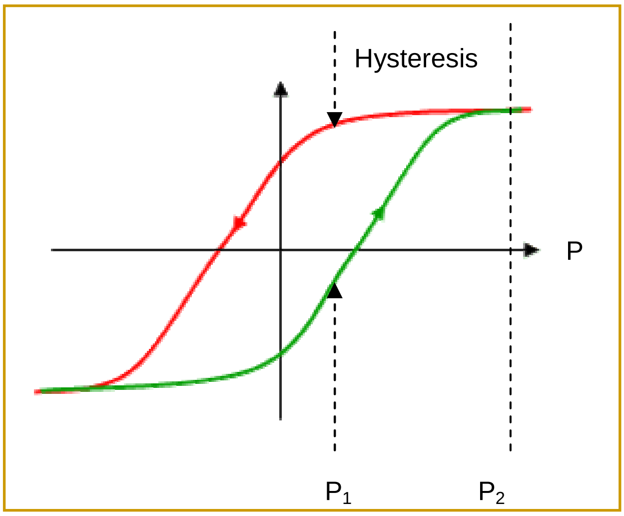


Diagram 3-1: Hysteresis Diagram.

3.4.1 Classification of Waveforms

Signals may be classified as two common types, namely analog or digital. Analog describes a signal that is continuous in time. Since physical variables tend to be continuous in nature, an analog signal, shown in Figure 3-2, provides their time- dependent behaviour. In addition the magnitude of the signal is continuous, thus can have any value within the operating range. Digital signals, shown in Figure 3-3, are particularly useful when data processing is performed by using a digital computer. A digital signal has two important characteristics.

First, a digital signal exists at discrete values in time. Second, the magnitude of a digital signal is discrete, determined by a process known as quantization at each discrete point in time.

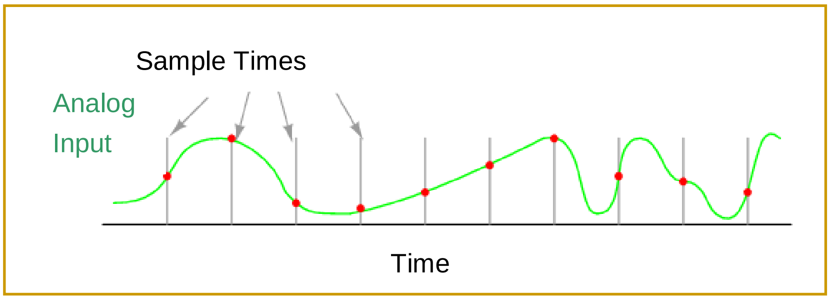


Figure 3-2: Analog signal.

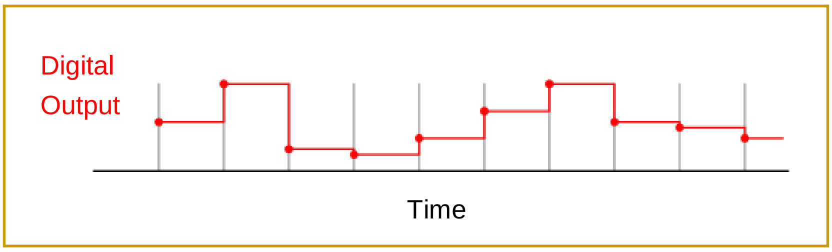


Figure 3-3: Digital signal.

3.5 Analog-to-Digital Converter

An analog-to-digital converter converts an analog voltage value into a binary number. The A/D converter has both an analog side (full-scale voltage range EFSR) and a digital side. The EFSR defines the voltage range over which the device will operate. An X-bit A/D converter can represent 2X different binary numbers. For example, a typical 8-bit A/D converter would be able to represent 28 = 256 different binary values.
The most common of different methods to perform the A/D conversion are as follows:

3.5.1 Successive Approximation Converters

The most common type of A/D converter uses the successive approximation technique (Figure 3-4) which uses a trial-and-error approach for estimating the input voltage to be converted. Basically, this type of A/D converter guesses successive binary values as it narrows in on the appropriate binary representation for the input voltage. This converter is typically used when conversion speed is important. Noise is the principal weakness of this type of converter.

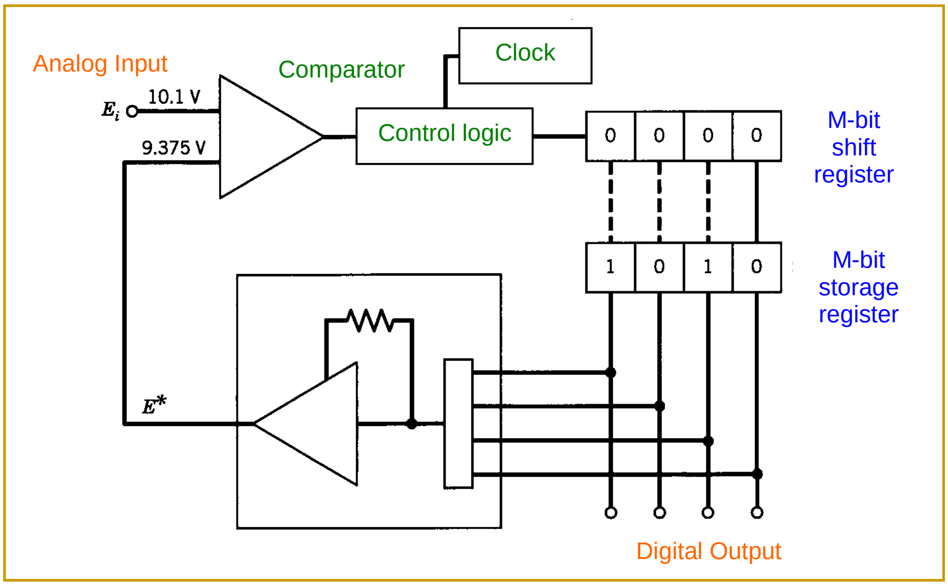


Figure 3-4: Successive approximation converter.

3.5.2 Ramp Converters

Ramp converters are usually used in high accuracy, low level (<1mV) measurements. These A/D converters use the voltage level of the analog input signal and convert it to its binary equivalent. It consists, as shown in Figure 3-5, of an analog comparator, ramp function generator and counter and M-bit register. The reference signal is increased at set time steps, within which the ramp level is compared with the input voltage level and this process is continued until the two are equal.

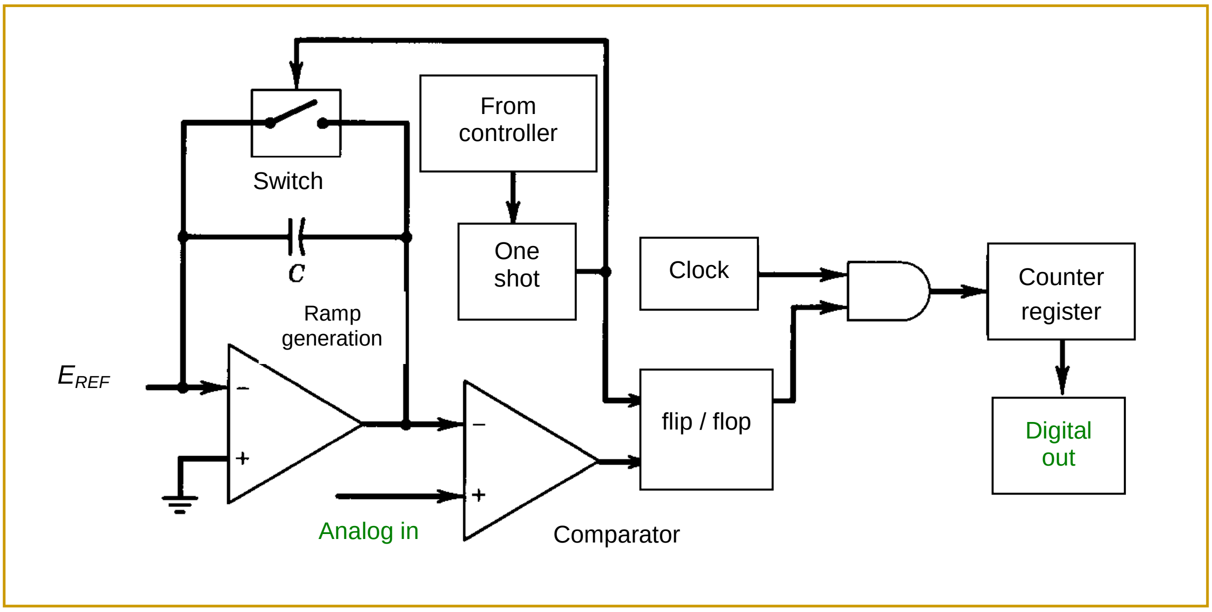


Figure 3-5: Ramp converter.

3.5.3 Parallel Converters

Parallel or flash converter is the fastest type of A/D converters. An M-bit parallel converter uses 2M-1 separate voltage comparators to compare a reference voltage to the applied input voltage. For example, an 8-bit converter will require 255 comparators. Logic scheme of a 2-bit parallel A/D converter is shown in the table below.

Comparator States			Binary Output
HIGH	HIGH	HIGH	11
LOW	HIGH	HIGH	10
LOW	LOW	HIGH	01
LOW	LOW	LOW	00

Table 3-1: Logic scheme of a 2-Bit parallel A/D converter.

4. MEASUREMENT PRINCIPLES

In this part of the work different measurement principles like as temperature-, pressure-, velocity-, flow-, strain- and force measurement methods and some other measurement techniques will be discussed.

4.1 Temperature Measurements

Temperature is one of the most commonly used engineering variable. This part of the thesis goes to explore the establishment of a practical temperature scale and common methods of temperature measurement.

4.1.1 Bi-metallic Thermometers

A bimetallic temperature sensor works on the physical principle of the differential thermal expansion of two metals. The sensor is constructed by bonding two strips of different metals, A and B, shown in Figure 4-1, one having a high coefficient of thermal expansion, another having a low coefficient, providing increased sensitivity. The following table shows some common metals used for this purpose and their temperature coefficient.

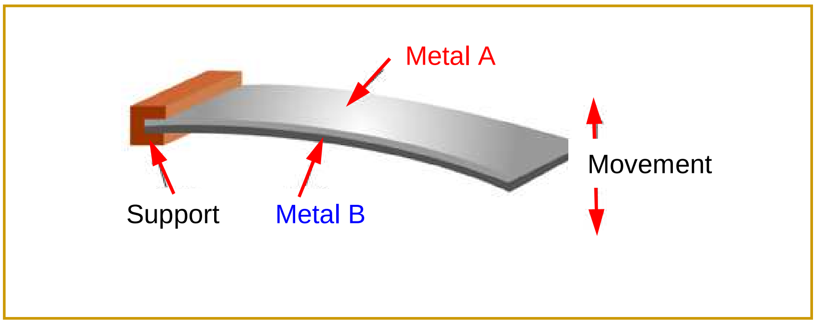


Figure 4-1: Bi-metallic Strip.

Copper	α = 0,00393	Gold	α = 0,0037
Aluminium	α = 0,00403	Coal	α = - 0,0013
Nickel	α = 0,00018	Constantan	α = 0,00001

Table 4-1: Temperature coefficient α (in 1/K at 20 ℃) of some materials.

4.1.2 Electrical Resistance Thermometry

Electrical resistance of a conductor or semiconductor varies with temperature. There are two basic classes of resistance thermometers using this behaviour: resistance temperature detectors (RTDs) and thermistors (semiconductors). RTDs may be formed from a solid metal wire which exhibits an increase in electrical resistance with temperature. The following equation shows the dependency of electrical resistance to some factors like resistivity and length of a material, as well as its cross-sectional area.

$$R = \frac{\rho_e l}{A_c} \tag{4.1}$$

ρ_e : Resistivity of a material, l : Length of a material, A_c : Cross-sectional area

4.1.2.1 Resistance Temperature Detectors (RTD)

Bridge circuits are used to measure the resistance of RTDs (Figure 4-2). Conventional ohmmeters cause a small current to flow during resistance measurements, creating self heating in the RTD. Wheatstone bridge circuits are commonly used for these measurements to minimize loading errors, and to provide low uncertainties in measured resistance values. The unknown resistance value of the RTD can be calculated with the help of three known values in the equation 4.2

$$\frac{R_1}{R_2} = \frac{R_3}{R_{RTD}} \tag{4.2}$$

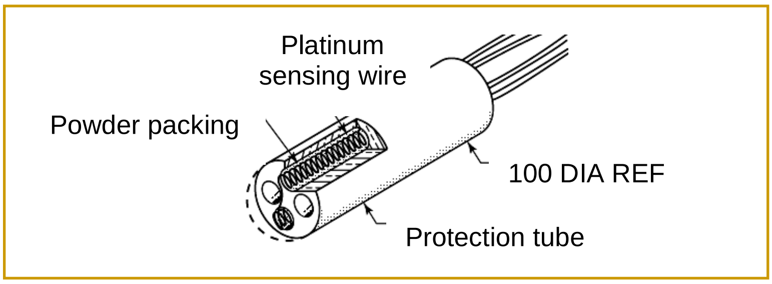


Figure 4-2: RTD-Wheatstone bridge arrangement

4.1.3 Thermistors

Thermistors (thermal resistors) are semiconductor devices which exhibits a large change in resistance proportional to a small change in temperature. Thermistors usually have negative temperature coefficients (NTC), which means the resistance of the thermistor decreases as the temperature increases as shown in Diagram 4-1.

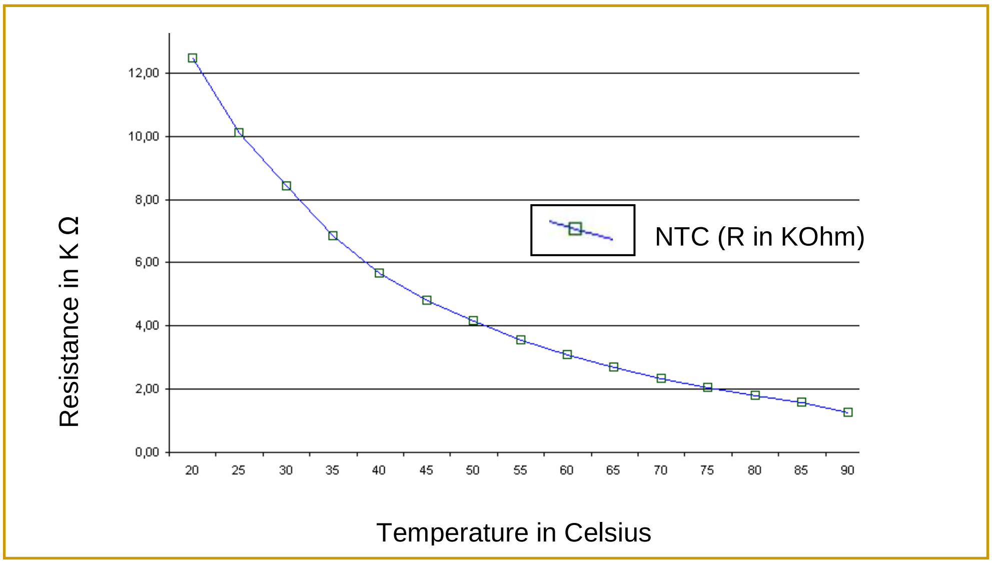


Diagram 4-1: Temperature-resistance diagram for a typical thermistor (NTC).

Thermistors are used in the industry in a wide range of applications such as: Flow meters, Vacuum gages, Motor thermal protection, Voltage regulation, Thermal switches, liquid level meter, air flow meter and many others.

4.1.4 Thermoelectric Temperature Measurement

Using an electrical circuit called a thermocouple is the most common method of measuring and controlling the temperature. A thermocouple, shown in (Figure 4-3), consists of two dissimilar electrical conductors with at least one electrical connection (junction). The junction may be created by any method that provides good electrical contact between the two conductors such as, welding, soldering or twisting the wires around one another.

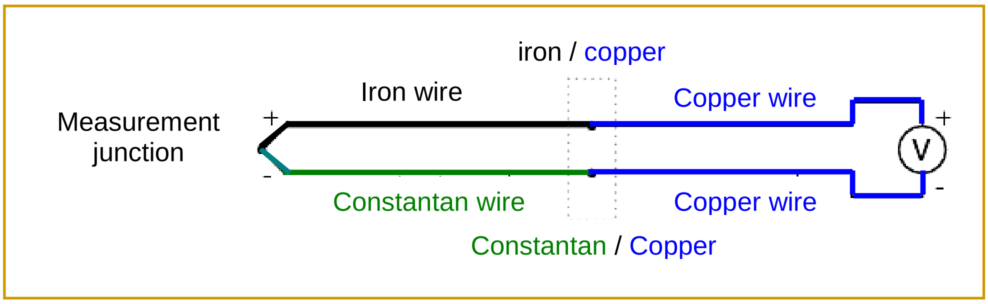


Figure 4-3: Thermocouple.

4.1.5 Hot-wire anemometer

This type of anemometer is used for the measurement of the velocity of air and other gaseous fluids. The element (either a metallic wire or another appropriate resistive sensing element like a thermistor) is incorporated into a Wheatstone bridge arrangement. The circuit for a constant current anemometer (Figure 4-4) shows that the sensor is heated from a constant current supply. “The current can be adjusted to heat the sensing element to the required temperature for a given application and the bridge is balanced by the balance adjust resistor”. [4] The bridge becomes unbalanced as the fluid velocity changes and finally leading to a change in output voltage, the magnitude of which is proportional to the square root of the fluid velocity.

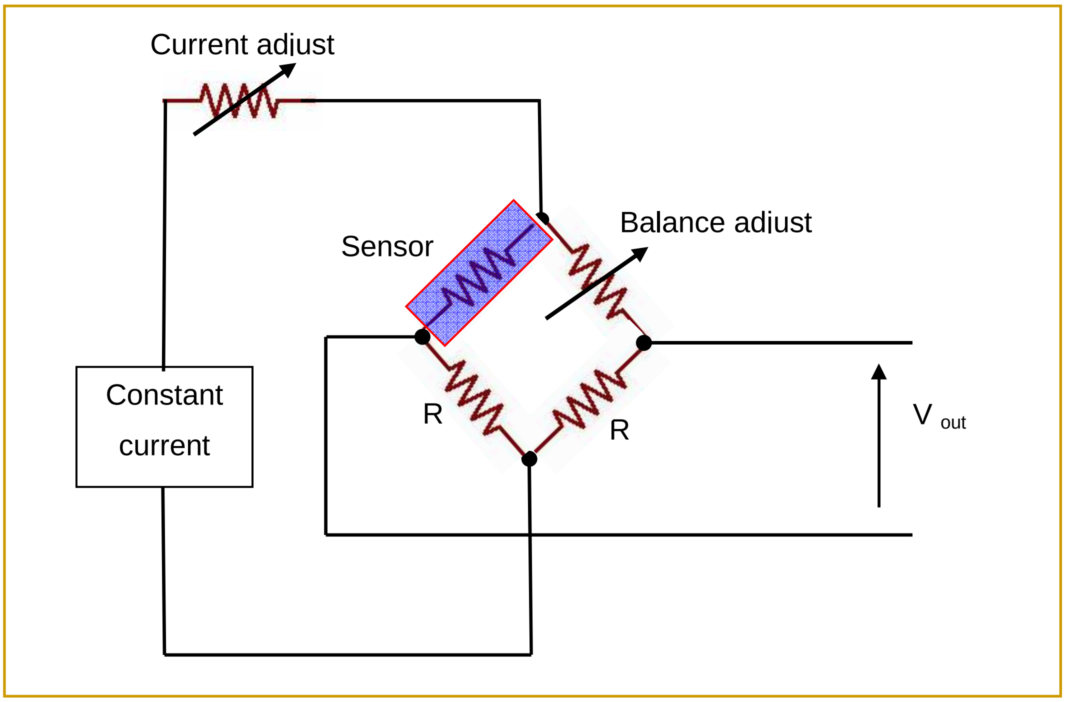


Figure 4-4: Hot-wire anemometer (constant current).

“The constant temperature anemometer (Figure 4-5) has a compensation resistor in the adjacent arm of the bridge to the sensing element. The components have similar temperature coefficients of resistance, thus allowing the effects of vibration in ambient operating temperature to be minimized as the two are sited in close proximity [5]”. Changes in the fluid velocity, changes the resistance of the sensing element and causing the bridge to become unbalanced. The control unit amplifies the error signal (bridge output) and adjusts the bridge supply voltage until the bridge is balanced. The excitation voltage is thus a function of the fluid velocity.

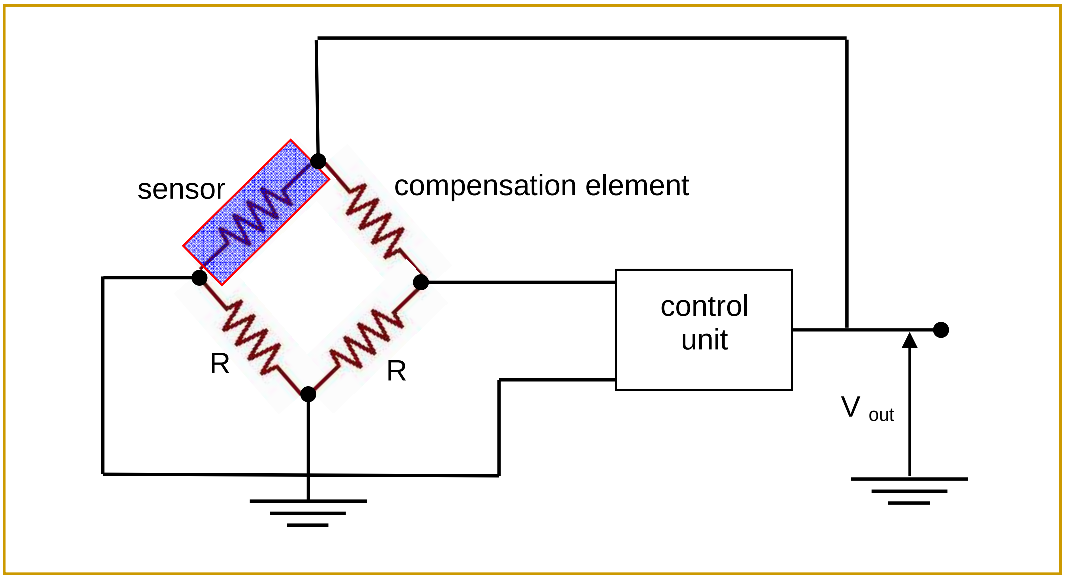


Figure 4-5: Hot-wire anemometer (constant temperature).

4.2 Pressure and Velocity Measurements

In this part of the thesis methods to measure the pressure as well as three well-established methods for the measurement of the local velocity within a moving fluid will be defined and analyzed.

4.2.1 Pressure Concepts

The pressure under standard atmospheric conditions is 1.01320 x 10^5 Pa (1 Pa =1N/m^2). Different pressure systems are shown in Diagram 4-2.

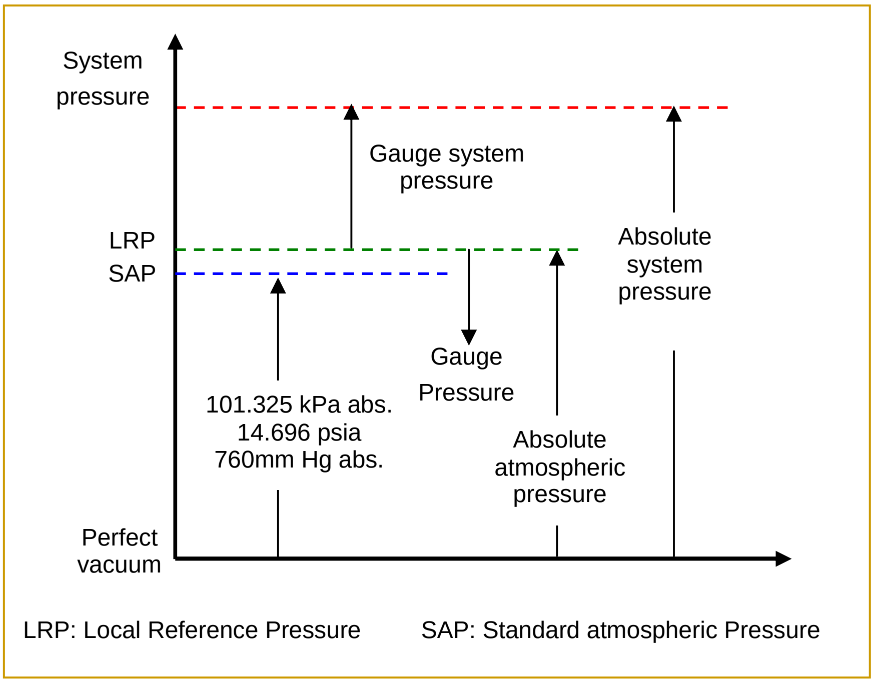


Diagram 4-2: Relative pressure scales.

The equation 4.3 shows the relation between an absolute pressure, p_{abs} and its corresponding gauge pressure, p_g

$$p_g = p_{abs} - p_0 \tag{4.3}$$

where p_0 is a reference pressure.

The local absolute atmospheric pressure is a commonly used reference pressure existing during the measurement.

A differential pressure, such as $p_1 - p_2$, is a relative measure and cannot be written as an absolute pressure.

Pressure (hydrostatic) can also be described in terms of the pressure exerted on a surface submerged in a column of fluid at a depth, h, as shown in Figure 4-6.

The equation 4.4 can be used to calculate the pressure at any depth within a fluid of specific weight γ:

$$p_{abs}(h) = p_0(h_0) + \gamma \cdot h \tag{4.4}$$

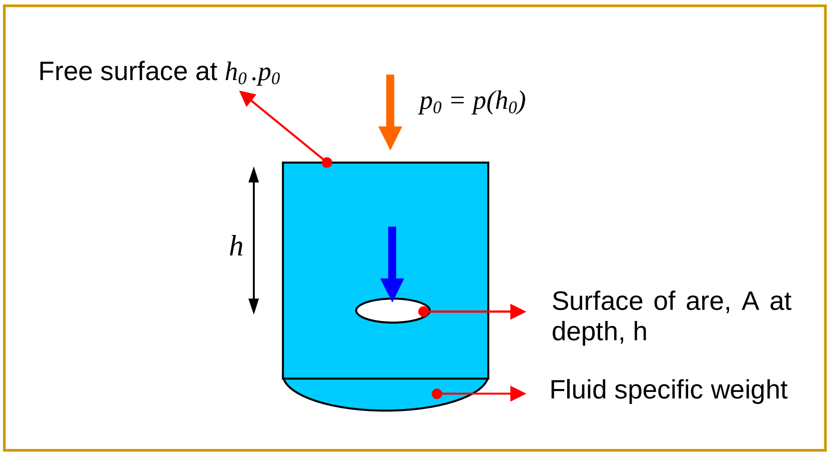


Figure 4-6: Pressure in a container

4.2.2 Pressure Transducers

Pressure, as well as temperature, is one of the most commonly used engineering variables. Pressure transducers are mainly used in hydraulic systems on the machines, for measuring the high pressured water/air on the underground machinery, in dedusting system, or dust suppression system in bulk materials handling machinery. This part of the work explain the common methods of pressure measurement with the help of pressure transducers. A pressure transducer converts a measured pressure into a mechanical or electrical signal.

4.2.2.1 Bourdon Tube

The Bourdon tube is a curved metal tube (such as the C shape, the spiral, and the twisted tube) that deforms under pressure. It is used as the primary sensor in a large class of pressure gauges. A pressure difference between the outside and the inside of the tube causes a deflection of the tube free end. The magnitude of the deformation is proportional to the magnitude of the pressure difference. The Bourdon tube mechanical dial gauge is a commonly used pressure transducer which is shown in Figure 4-7.

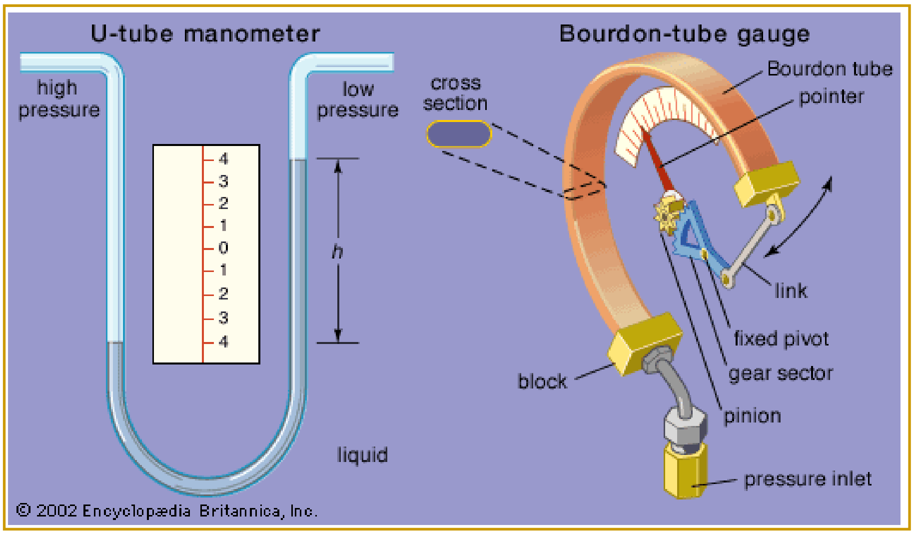


Figure 4-7: Bourdon tube.

4.2.2.2 Strain Gauge Elements

Converting the diaphragm displacement into a measurable signal is the main goal of using the strain gauge elements in which it senses the strain induced on the diaphragm surface as it is displaced.

Semiconductor strain gauges (very small, very fast, highly sensitive strain gauge diaphragm transducers) have a sensitivity that is 50 times greater than conventional metallic strain gauges. A silicon diaphragm, for example, (there are metallic and non-metallic diaphragms) will not creep with age (as will a metallic gauge), thus minimizing calibration drift over time.

4.2.2.3 Capacitance Elements

A capacitor that forms an effective secondary element is created when one or more fixed metal plates are placed directly above or below a metallic diaphragm. The capacitance, C between two parallel plates separated by a distance, t, is determined by the following equation. Displacement of the diaphragm changes the average gap separation.

$$C = c\varepsilon A / t \tag{4.5}$$

Where, ε is the dielectric constant (for air, ε =1), A is the overlapping area, and c is the proportionality constant.

Small size and a very wide operating range are the advantages of these elements. However it is sensitive to temperature changes.

4.2.2.4 Piezoelectric Crystal Elements

A piezoelectric crystal (Figure 4-8) will deform under the action of compression, tension, or shear and develop a surface change, q, which is proportional to the force acting to bring about the deformation. In a piezoelectric pressure transducer, a preloaded crystal is mounted to the diaphragm sensor. Pressure acts normal to the crystal axis and changes the crystal thickness, t, by a small amount Δt, which develop a voltage across the electrodes (Equation 4.6).

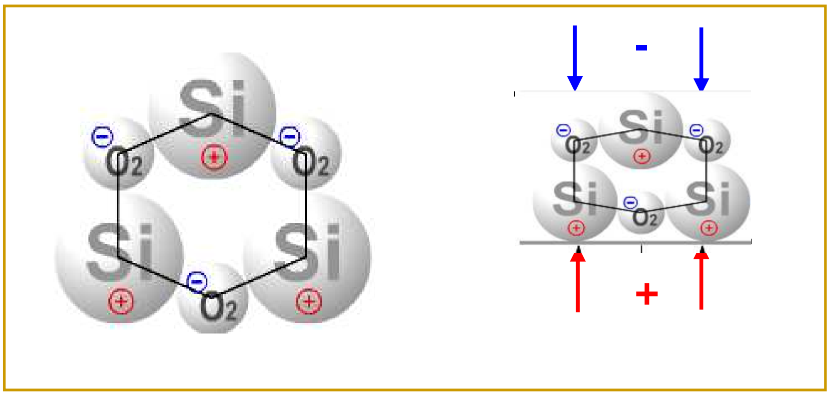


Figure 4-8: Piezoelectric crystal.

$$E_0 = \frac{q}{C} \tag{4.6}$$

Where, C is the capacitance of the crystal-electrode combination.

4.3 Flow Measurements

Flow rate can be expressed in terms of a volume per unit time, known as the volume flow rate, or as a mass per unit time, known as the mass flow rate. This part of the thesis discusses some of the most common methods for flow quantification.

4.3.1 Pressure Differential Meters

"The operating principle of a pressure differential meter is based on the relationship between volume flow rate Q and the pressure drop $\Delta p = p_1 - p_2$, along the flow path.

$$Q \approx (p_1 - p_2)^n \tag{4.7}$$

where, n equals one for laminar flow occurring between the pressure measurements location, and is one-half in fully turbulent flow [6]". The Bernoulli-effect says that a reduction in flow area will cause a measurable local pressure drop across the flow path and causes a local increase in velocity.

4.3.1.1 Orifice Meter

An orifice meter, shown in Figure 4-9, consists of a circular plate with a hole (orifice), which is located concentric with the pipe inside diameter. There are several variations in the orifice design such as the square-edged orifice. The installation can be simplified by housing the orifice plate between two pipe flanges.

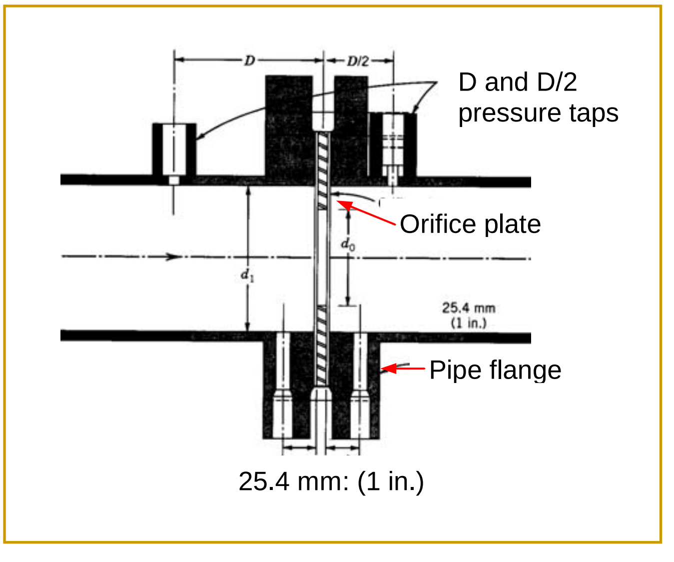


Figure 4-9: Orifice Meter.

4.3.1.2 Venturi Meter

"A Venturi meter, shown in Figure 4-10, consists of a smooth converging contraction to a narrow throat followed by a shallow diverging section. The standard Venturi can utilize either a 15° or 7° divergent section. The meter is install ed between two flanges intended for this purpose. The quality of Venturi meters range from cast units to precision machined units [7]".

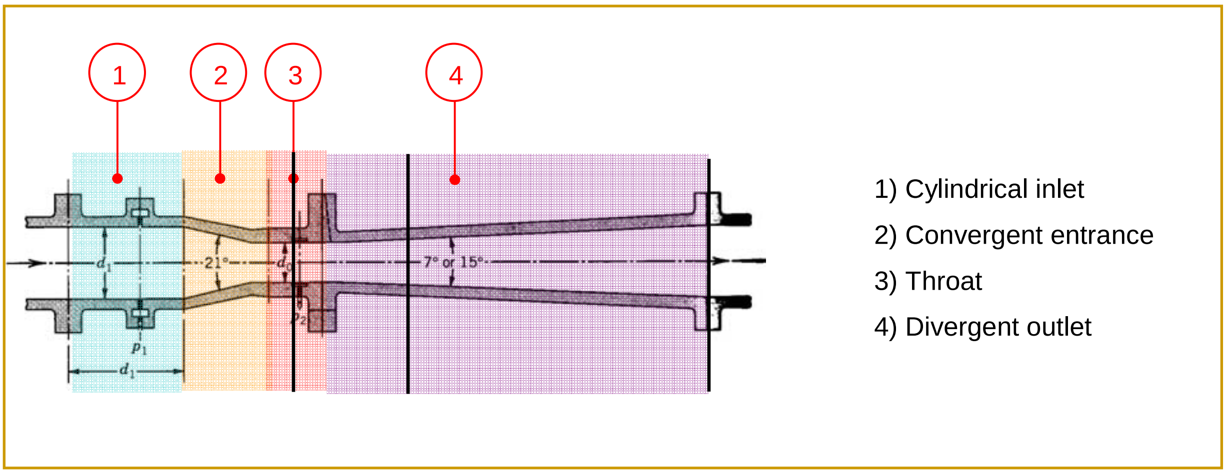


Figure 4-10: Venturi design.

4.3.2 Insertion Volume Flow Meters

Most of the meters are based on some phenomenon that is actually sensitive to the average velocity across a control surface of known area. In the following pages, the two most important types of volume flow meters will be discussed.

4.3.2.1 Electromagnetic Flow Meters

Electromagnetic flow meters work on the fundamental principle that an emf of electric potential, E, is induced in a conductor of length, L, which moves with a velocity, U, through a magnetic field of magnetic flux, B, with the relation shown below:

$$E = U \times B \cdot L \tag{4.8}$$

The electromagnetic flow meter, which is installed directly in line and connected to an external electronic output unit, comes commercially as a packaged device. The operating principle is independent of fluid density and viscosity, responding only to average velocity. The so called DC units work with permanent magnets and the so called AC units using variable flux strength electromagnets.

4.3.2.2 Turbine Meters

Turbine meters have housing contains flanges for direct in-sertion into a pipeline. They make use of angular momentum principles to meter the flow rate. “In a typical design, a rotor is encased within a bored housing through which the fluid to be metered is passed. The exchange of momentum between the flow and the rotor turns the rotor at a rotational speed that is proportional to the flow rate [8]”.

Sensing the passage of magnetic rotor blades (for example with the help of a reluctance pickup coil) and producing a pulse train signal at a frequency that is directly related to rotational speed is one of the ways measuring the rotor rotation. Low-pressure drop and a very good accuracy are the advantages of turbine meters. “However their use must be restricted to clean fluids because of possible fouling of their rotating parts. Temperature changes affect fluid viscosity, a property to which a turbine meter rotational speed is sensitive [9]”.

4.3.3 Mass Flow Meters

Measuring the mass flow rate is also important in some situations. Thermal flow meter and Coriolis flow meter are two methods for measuring the mass flow of a fluid flowing in a pipe, which will be discussed in this part of the thesis.

4.3.3.1 Thermal Flow Meter

The equation 4.9 shows, that “the rate at which energy $\dot{E}$ must be input to a flowing fluid to raise the temperature of the fluid some desired amount between two control surfaces is directly related to the mass flow rate [10]”.

$$\dot{E} = \dot{m} c_p \Delta T \tag{4.9}$$

Where c_p is the fluid specific heat and remains constant over the length of a meter and $\dot{m}$ is the mass flow rate. Passing of a current through an immersed filament (hot-film) is a common method for measuring the mass flow rate in which the fluid temperature are measured at the upstream and the downstream locations of the meter.

4.3.3.2 Coriolis Flow Meter

The Coriolis flow meter, shown in Figure 4-11, works on the principle of metering mass flow rate by inducting Coriolis acceleration on the flowing fluid and measuring the resulting developed force.

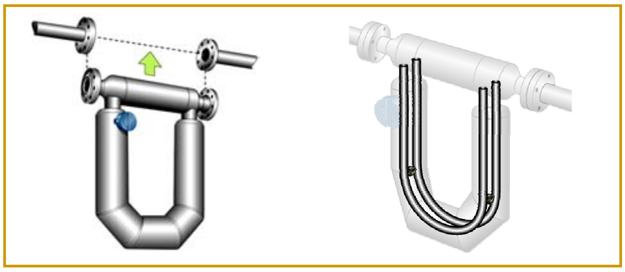


Figure 4-11: Coriolis flow meter.

Operation:

The Coriolis flow tubes are balanced (by vibrating in opposition to one another) and isolated from external vibration or movement of the flow meter. The fluid entering the sensor is split with half of the fluid passing through each flow tube. Pick-off coils are mounted on the side legs of one flow tube, and magnets are mounted on the side legs of the opposing flow tube. Each coil (the one on the inlet side and the one on the outlet side) moves through the uniform magnetic field of the adjacent magnet and create sine wave signals, shown in Figure 4-12, continuously when the tubes are oscillating.

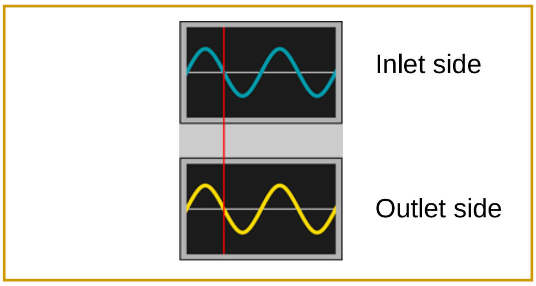


Figure 4-12: Inlet and outlet sine waves in no-flow condition.

When no flow, there is no Coriolis-Effect. Thus the inlet motion and outlet motion is in phases and the sine waves coincide with each other. “When fluid is moving through the sensor's tubes, Coriolis forces are induced in both the inlet and outlet legs of both flow tubes. These forces cause the flow tubes to twist in opposition to each other. The mass flow moving through the inlet legs of the flow tubes generate a Coriolis force that resists the vibration of the flow tubes. As the mass flow moves through the outlet legs, the Coriolis force adds to the vibration of the flow tubes. It is the opposite direction of the Coriolis force between the inlet and outlet legs that result in the twisting motion that is used to measure mass flow rate. As a result of the twist in the flow tubes, the sine waves generated by the pickoffs are now out of phase with each other because the inlet legs are lagging behind the outlet legs. The time delay between the two sine waves is measured in microseconds, and is called Delta-T, shown in Figure 4-13. Delta-T is always directly proportional to the mass flow rate – the greater the Delta-T created by the Coriolis force, the greater the mass flow rate. This calibration factor (each sensor has a unique calibration factor), multiplied by a Delta-T measured in micro seconds, yields mass flow rate in grams/sec. This mass flow rate is then converted into the desired units by the transmitter [11]".

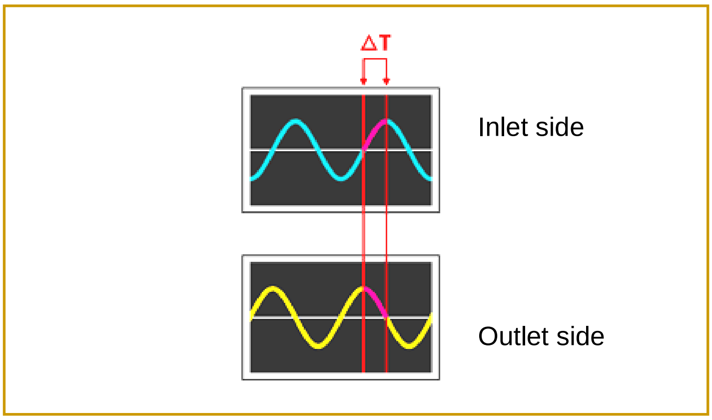


Figure 4-13: Sine waves time delay by Coriolis meter.

4.4 Strain Measurement

Proper design of devices, such as shafts and support structures, must consider allowable deflections. Mechanics of materials provides a basis for predicting these essential characteristics of a mechanical design and provides a fundamental understanding of the behaviour of load-carrying parts. Let's have a brief look on the terms stress and strain and the relationship among them before discussing the relevant measurement systems.

The equation 4.10 shows the relationship among the stress, the force and the cross-sectional area of the device.

$$\sigma_a = \frac{F_N}{A_c} \tag{4.10}$$

A_c = Cross-sectional area of rod

F_N = Tension force applied to the rod

The equation 4.11 defines the axial strain which is the ratio of the change in length of the material (which results from applying the load) to the original length L.

$$\varepsilon_a = \frac{\delta L}{L} \tag{4.11}$$

The following diagram (Diagram 4-3), shows the elastic and plastic region of the material under tension. Hooke´s law applies only over the range of applied stress where the relationship between stress and strain is linear.

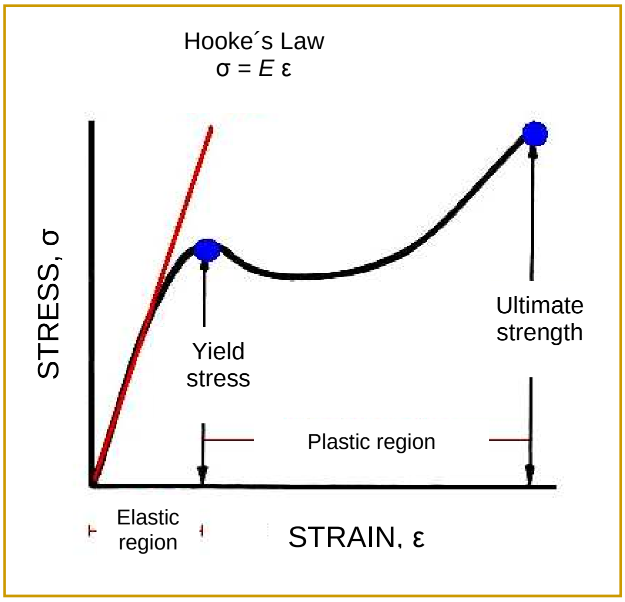


Diagram 4-3: Typical stress-strain curve.

4.4.1 Resistance Strain Gauges

Both metallic and semiconductor materials experience the change in electrical resistance when they are subjected to a strain. These changes depend on how the gauge is deformed, its material and its design. Gauges can be made quite small with a low mass to obtain a good resolution and to provide a high frequency response.

4.4.1.1 Metallic Gauges

Figure 4-14 shows a metallic strain gauge. It is in fact a conductor having a uniform cross-sectional area, Ac and a Length, L, made of a material having a resistivity (ρ). The resistance R is given by the following equation for this electrical conductor:

$$R = \rho_e \frac{L}{A_c} \tag{4.12}$$

If the conductor is subjected to a normal stress along the axis of the wire, the cross-sectional area and the length will change, resulting in a change in the total electrical resistance, R.

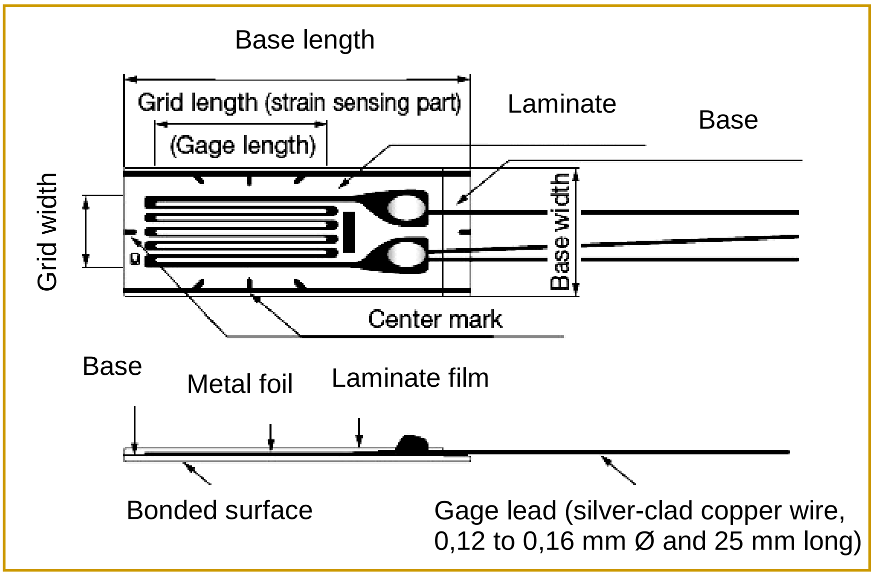


Figure 4-14: Metallic strain gauge.

4.4.2 Semiconductor Strain Gauges

The basic material for semiconductor strain gauges are silicon crystals; “the crystals are sliced into very thin sections to form strain gauges. Because of the high piezoresistance coefficient, the semiconductor gauge exhibits a very high gauge factor[1], as high as 200 for some gauges. These gauges also exhibit higher resistance, longer fatigue life and lower hysteresis under some conditions than metallic gauges. However the output of the semiconductor strain gauge is nonlinear with strain, and the strain sensitivity or gauge factor may be markedly dependent on temperature [12]”.

1) The gauge factor (GF) or the strain sensitivity, as shown in equation 4.13, represents the total change in resistance for a strain gauge, under a calibration loading condition.

$$GF \equiv \frac{\delta R / R}{\delta L / L} = \frac{\delta R / R}{\varepsilon_a} \tag{4.13}$$

4.4.3 Strain Gauge Electrical Circuits

The small changes in resistance which are the output of a strain gauge measurement circuit can be generally detected with the help of a high sensitivity device such as a Wheatstone bridge, shown in Figure 4-15.

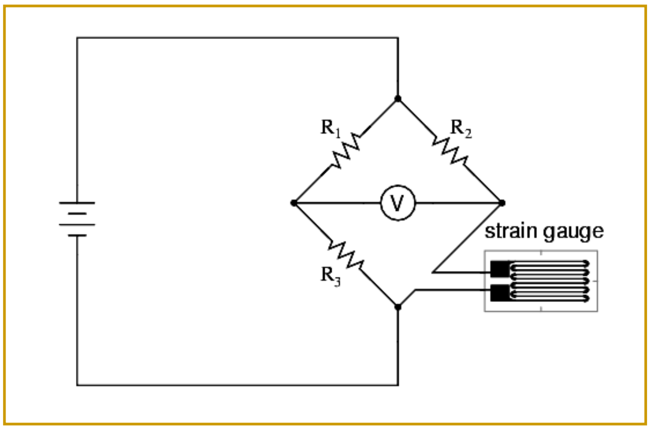


Figure 4-15: Strain gauge electrical circuit.

4.5 Motion, Force and Power Measurements

In this section, common techniques for the measurement of mass, force, torque and power will be discussed. Measurement methods for displacement, linear and angular velocity, vibration and acceleration will also be described.

4.5.1 Displacement Measurements

Two common methods used in this work for measurement of displacement purposes are based on the determination of the relative motion of two points, of which one is usually fixed, which are used for example in the displacement transducers mounted on the apron hydraulic cylinder or on the sump slide hydraulic cylinders on the AVSA machines in underground mining activities.

4.5.1.1 Potentiometer

A variable electrical resistance transducer or potentiometer, shown in Figure 4-16, is composed of a winding (made of many turns of wire, wrapped around a non-conducting material) and a sliding contact or wiper. Output signals can be realized by imposing a known voltage across the total resistance of the winding and by measuring the output voltage, which is proportional to the fraction of the distance the contact point has moved along the winding. The resolution of the device is limited by the number of turns per unit distance.

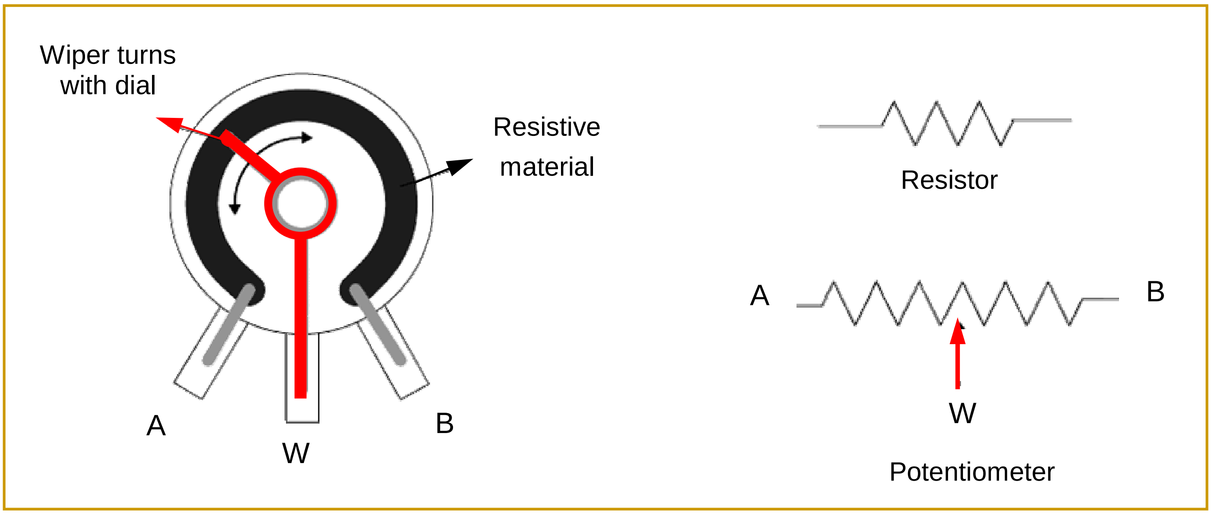


Figure 4-16: Potentiometer.

4.5.1.2 Linear Variable Differential Transformers

The LVDT, shown in Figure 4-17, produces an AC output (sinusoidal wave) with amplitude that is proportional to the displacement of a moveable core. The movement of the core causes a mutual inductance in the secondary coils 1 and 2 (connected in a series circuit, such that when the iron core is centered between the two secondary coils the output voltage amplitude is zero) for an AC voltage applied to the primary coil. According to faraday's law for two coils in close proximity, a change in the current in one coil will induce an emf in the second coil. Over the range of operation, the output amplitude is essentially linear with core displacement. Beyond this linear range, the output amplitude will rise in a nonlinear manner to a maximum and eventually fall to zero as shown in Figure 4-18.

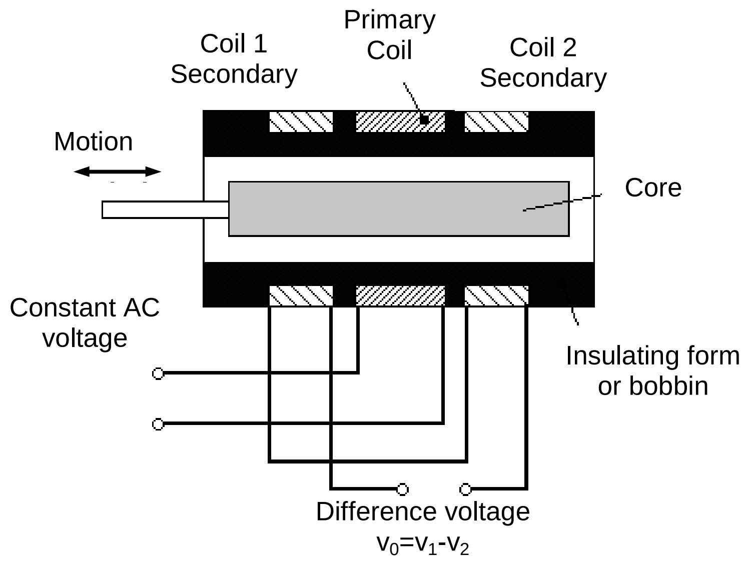


Figure 4-17: Lineal variable differential transformer.

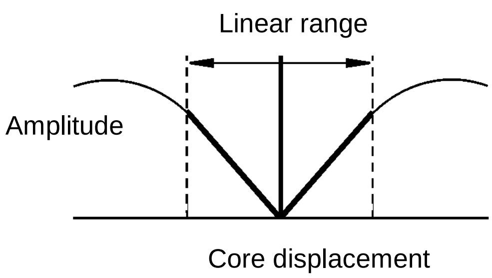


Figure 4-18: Amplitude change with core displacement.

The advantage of using an LVDT displacement transducer is first that the moving core does not make contact with other electrical components of the assembly, so it offers high reliability and long life. Second, the core can be so aligned that an air gap exists around it, which is ideal for applications where minimum mechanical friction is required.

4.5.2 Force Measurements

Force is a quantity derived from the fundamental dimensions mass, length and time. In this part of the work, the most common methods for force measurement will be described.

4.5.2.1 Load Cells

The term load cell describes a transducer that generates a voltage signal as a result of an applied force, which often consist of an elastic member and a deflection sensor. These deflection sensors may employ changes in capacitance, resistance or the piezoelectric effect to sense deflection.

4.5.2.2 Strain Gauge Load Cells

These load cells are made of a metal and have a shape such that the forces to be measured results in a measurable output voltage over the desired operating range. “The shape of the linearity elastic member is designed to meet the following goals:

1. Provide an appropriate range of force measuring capability with necessary accuracy
2. Provide sensitivity to forces in a particular direction, and have low sensitivity to force components in other directions [13]”.

Load cells may be characterized as beam-type load cells (bending beam load cells, shown in Figure 4-19, shear beam load cells, proving rings or columnar-type designs.

Normal or bending stresses can be measured with mounting strain gauges on the top and bottom of the beam. The bending stresses are linearly related to the applied load in the linear elastic range of the load cell.

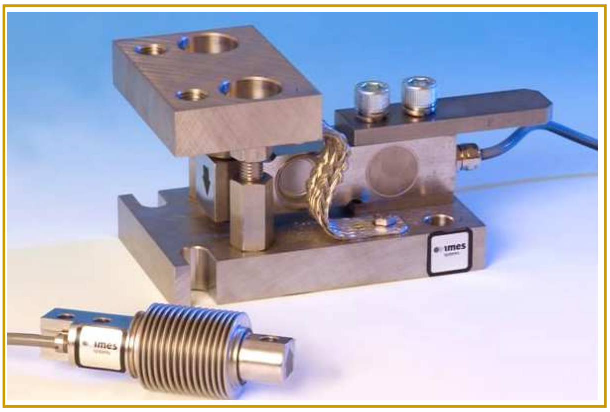


Figure 4-19: Bending beam load cell.

In general bending beam load cells are less costly because of their construction; however, the shear beam load cells have several advantages, including lower creep and faster response times. The Figure 4-20 shows how the bridge gets unbalanced under bending stresses.

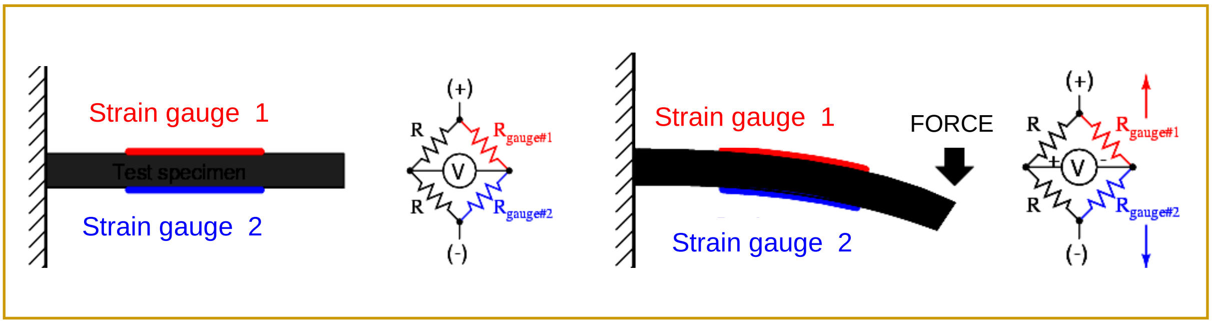


Figure 4-20: Strain gauge on bending beam.

The Figure 4-21 illustrates a half- /full bridge strain gauge circuits, which can be used on beams under bending, shear or torsion stresses.

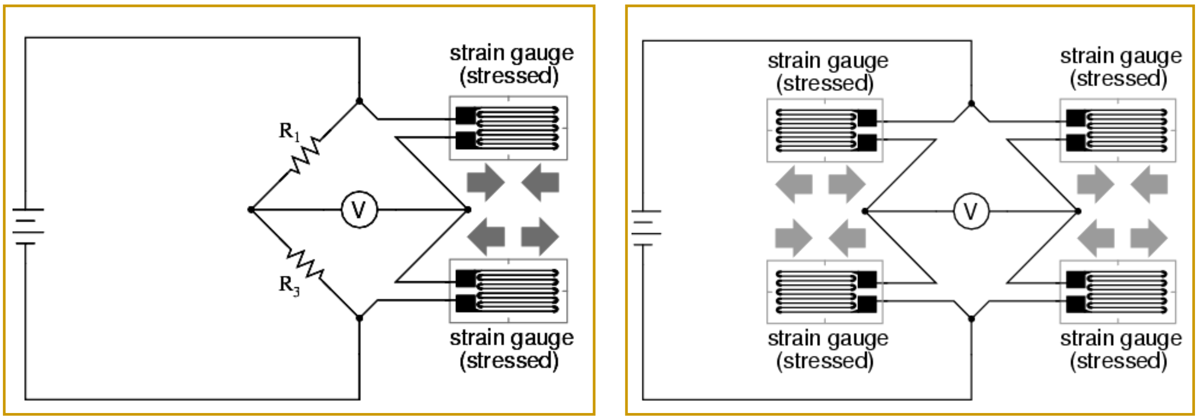


Figure 4-21: Half-/full bridge strain gauge circuits.

4.5.2.3 Piezoelectric Load Cells

For piezoelectric devices, a piezoelectric material (single-crystal quartz) is compressed and generates a charge that is conditioned by a charge amplifier. Piezoelectric materials are characterized by their ability to develop a charge subject to a mechanical strain. The basic principle of transduction, which occurs in a piezoelectric element, may best be thought of as a charge generator and a capacitor with a very high frequency response of transducers up to 15,000 Hz.

4.5.2.4 Proving Ring

The proving ring (ring-type load cell), which has a high degree of precision and accuracy, is often used in the calibration of materials testing machines. The relationship between the applied force F_n and deflection δy is given by equation 4.14, If the sensor is approximated as a circular right cylinder.

$$\delta y = (\frac{\pi}{2} - \frac{4}{\pi})\frac{F_n D^3}{16EI} \tag{4.14}$$

D …diameter

E …modulus of elasticity and

I …moment of inertia

4.6 Swing angle pickup sensor

4.6.1 Potentiometric displacement sensor

The swing angle pickup sensor (Figure 4-22) works in principle like a displacement sensor. An easy way of measuring an angle can occur by a potentiometric transmitter with the use of wire or carbon film as the resistance element. Potentiometric angle pickup sensors can measure the angles of 0° to 350°. High lifespan, hi gh ability for reproduction of the measuring values and low hysteresis is the most important characteristics of these angle measuring sensors.

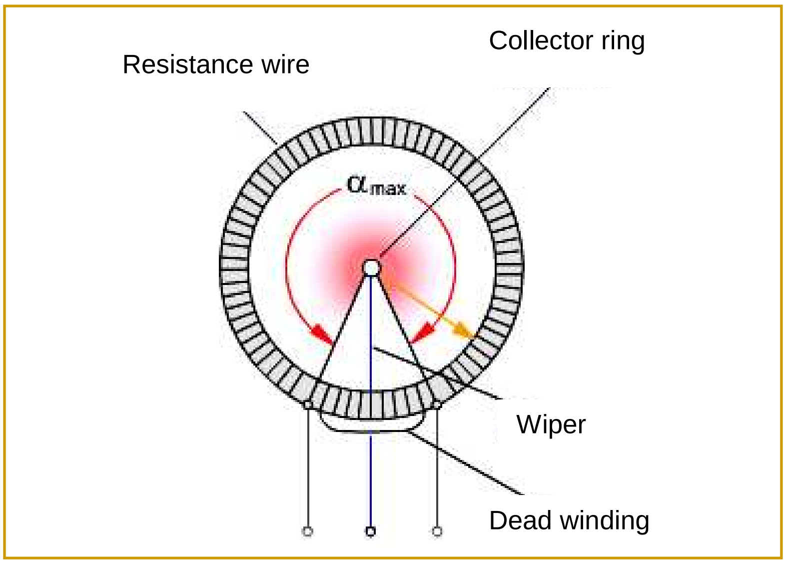


Figure 4-22: Potentiometric displacement sensor.

4.6.2 Inductive displacement sensor

Using inductive transmitters is another principle for measuring an angle (inductive half-bridge). This angle pickup sensor, shown in Figure 4-23, consists of two reels which turns a rotor made of two metals with different magnetic permeability. The rotation of the rotor generates a counteract induction change in both reels. The induction change can be converted by the built-in electronics in a signal which is proportional to the rotary angle. Because of the symmetrical construction, the zero point is in the middle and thereby makes the measuring of +/- 45° possible.

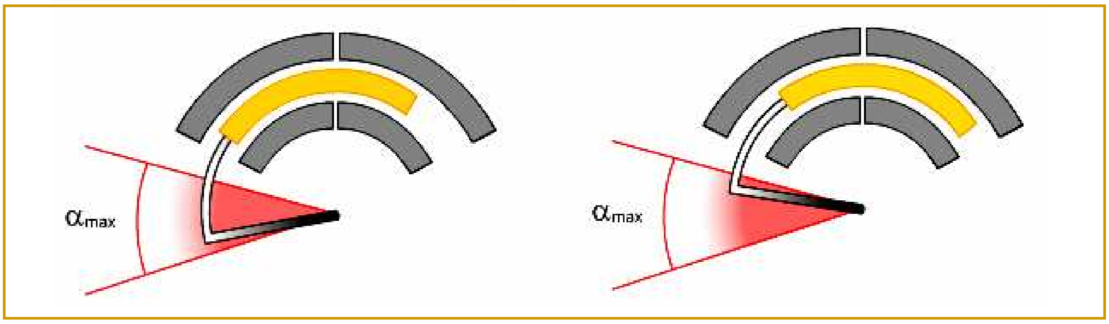


Figure 4-23: Inductive displacement sensor.

4.7 Incremental position encoder (Displacement sensor)

Incremental displacement sensors, as shown in Figure 4-24, deliver digital signals unlike to inductive or potentiometric displacement sensors. The measuring process is based on the fact that a source of light (emitter) and a component sensitive to light (receiver) is moved relatively to a glass measuring unit on which strings are in the same distances (scale). The number of the lines crossed from the transmitter and receiver is proportional to the passed distance. The smaller the grid, the greater is exactness of the displacement sensor. However, the Incremental measuring procedures has the disadvantage that only one relative displacement difference can be determined between two points. The incremental position encoder has also a disadvantage namely; it gives only the relative distance between two points.

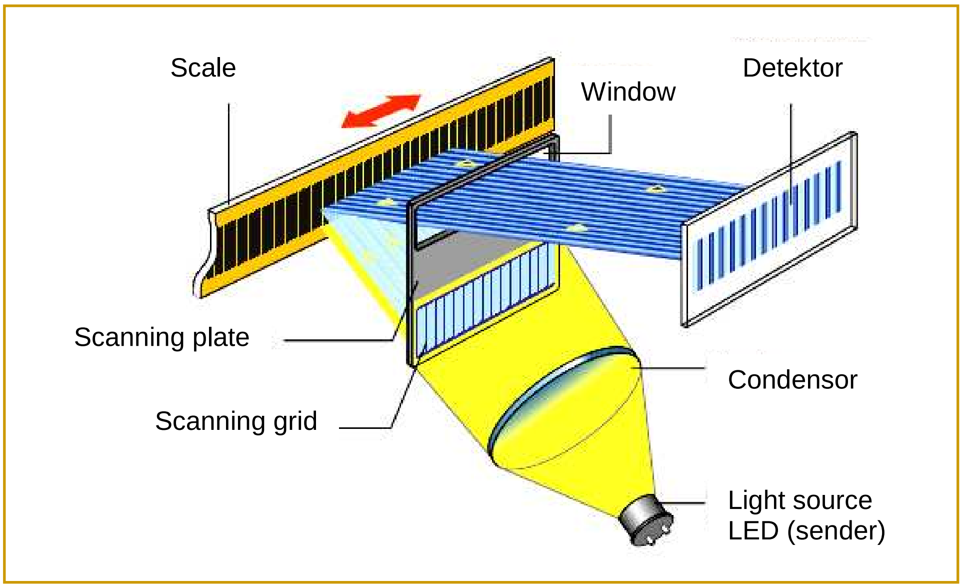


Figure 4-24: Displacement Sensor.

4.8 Absolute value position encoder

The absolute value displacement sensor is built up like the incremental displacement sensor. A transmitter and a receiver move over a coded grid ruler which is divided into tracks. Thereby, a binary numerical value is assigned to every step. The length which can be measured is thereby dependent on the number of the tracks on the grid ruler. With n tracks we have 2^n length positions distinguishable of each other.

4.9 Multiturn absolute encoder

In principle, in a Multiturn absolute encoder Figure 4-25, a light shines through an etched disc and makes a combination of ON and OFF signals. “The disk indicates shaft position by encoding a unique binary digit that matches the amount of rotation. However, multi-turn encoders not only determine shaft position, but also how many times the shaft rotates 360°. Most multi-turn encoders use a system of gears to count the number of complete turns. A primary gear meshes with the encoder shaft which, in turn, moves a secondary gear, and so on. Each gear is an etched disc whose rotation is tracked by the encoder electronics. The encoder combines the output of all discs to count the number of turns the shaft makes [14]”.

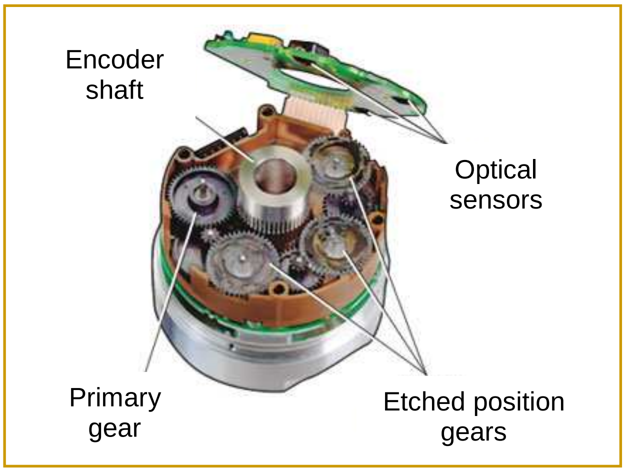


Figure 4-25: Multiturn absolute encoder.

4.10 Limit switch

A limit switch is an electro-mechanical device that consists of an actuator mechanically linked to a set of contacts. When an object comes into contact with the actuator, the device operates the contacts to make or break an electrical connection. The Figure 4-26 shows four different kinds of switches. Limit switches, as shown in Figure 4-27, are used in a variety of applications on surface mining machinery because of their ruggedness, simple visible operation, ease of installation and reliability of operation.

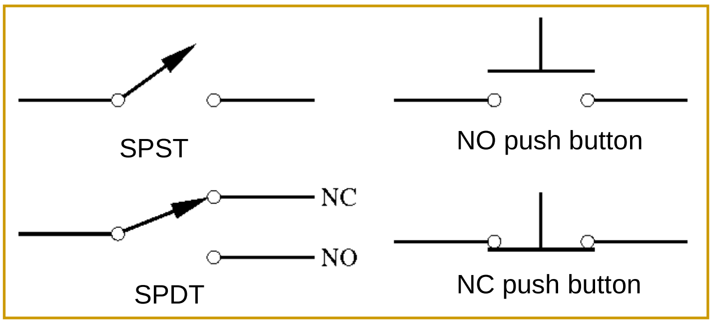


Figure 4-26: Limit switch electrical symbols.

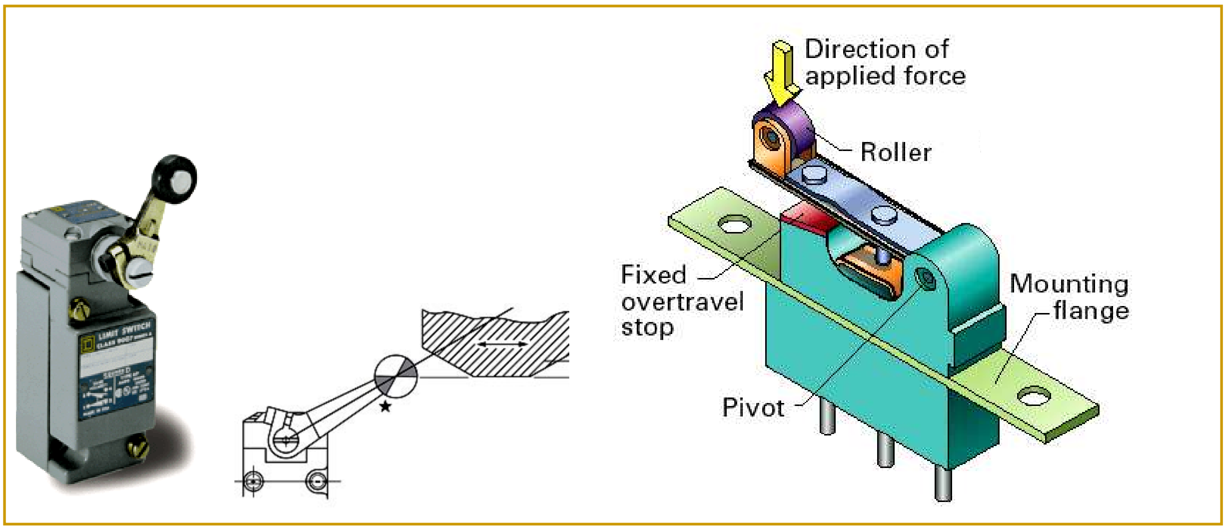


Figure 4-27: Limit switch with actuator.

4.10.1 Universal (TU) and standard (TS) switches

Universal switch (Figure 4-28) has adjustable latches (A) and a return spring positioning plate (B). It is adjustable to one of eleven different operating sequences. The standard switch (Figure 4-28) has only adjustable latches (A). It differs from the universal switch in that contact action is identical when the operating arm moves clockwise or counter clockwise. Because of this feature, the standard switch is adjustable only to three different operating sequences.

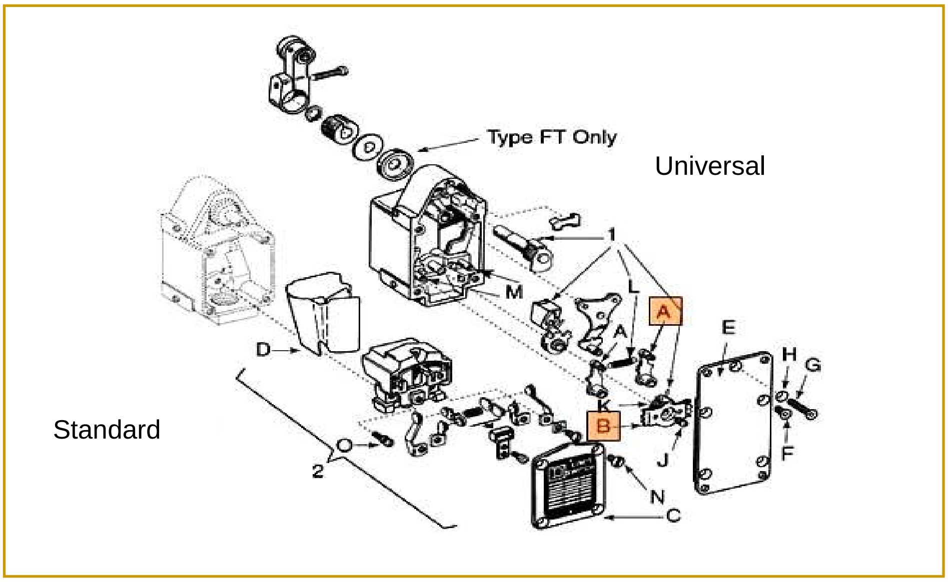


Figure 4-28: Limit switch (standard, universal).

4.11 Relay

A relay (Figure 4-29) is an electrical switch that opens and closes under the control of another electrical circuit. In the original form, the switch is operated by an electromagnet to open or close one or many sets of contacts. Because a relay is able to control an output circuit of higher power than the input circuit, it can be considered, in a broad sense, to be a form of an electrical amplifier.

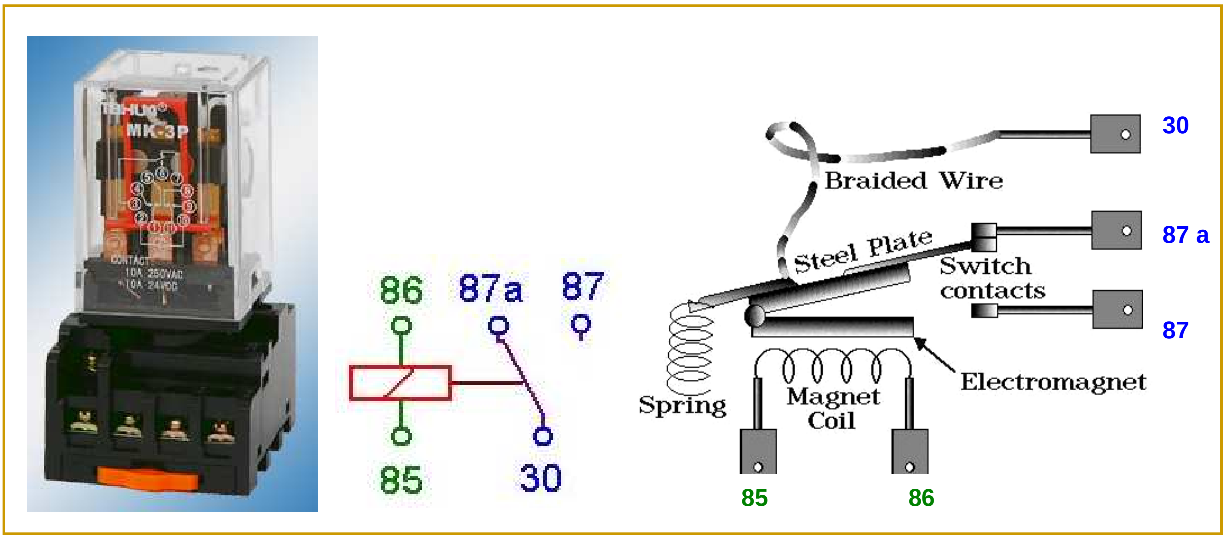


Figure 4-29: Electrical relay (L); Schematic illustration of a Relay (R).

4.11.1 Contactor relay

A very common type of relay used on the machines described in this work is a contactor relay. It is a very heavy-duty relay used for switching electric motors and lighting loads with high current. The contacts are made with pure silver because the unavoidable arcing causes the contacts to oxidize and silver oxide is still a good conductor. The overload sensing devices are a form of heat operated relay where a coil heats a bi-metal strip, or where a solder pot melts, releasing a spring to operate auxiliary contacts. These auxiliary contacts are in series with the coil. If the overload senses excess current in the load, the coil is de-energized.

4.12 Inductive proximity switch

Proximity sensors are sensors able to detect the presence of near objects (electrically conducting bodies) without any physical contact. By all inductive sensors (Figure 4-30) a change of the magnetic field is evaluated as a signal.

This field is generated by an LC-oscillator in an inductive proximity switch. The arrangement of coils generates a high frequency magnetic field on the active surface of the sensor and also in front of it.

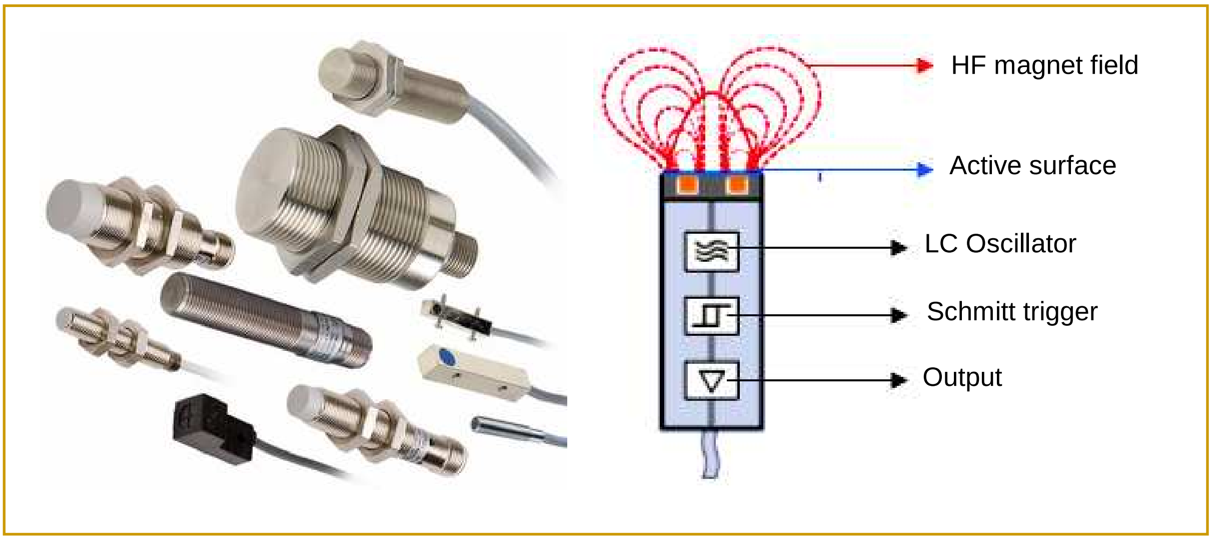


Figure 4-30: Inductive proximity switch.

When electrically conducting materials are brought in the field, then they disturb the magnetic field and generate a signal. The disturbance factor depends on the inductivity of different materials. The nominal switching distance can be given by a norm plate as shown in Figure 4-31.

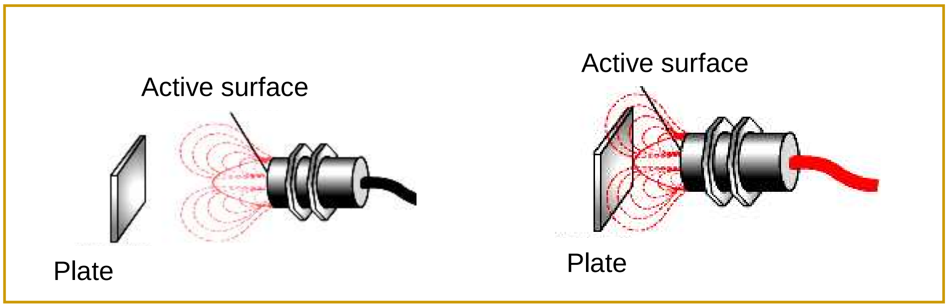


Figure 4-31: Nominal switching distance.

Function: Detection of all types of metallic objects.

Applications: Automated equipment, robotics, welding applications, rotation control, conveying, metering, positioning, presence of parts, dimensioning.

Advantages: contact free detection of objects, no wear and tear, very short reaction time, have a long life expectancy, irrespective of the number of detections, insensitive to dust and humidity, LED condition display.

4.13 Capacitive proximity switch

By all capacitive sensors (Figure 4-32), a change of the electric field between two electrodes (capacitor) is evaluated. An RC oscillator generates electric field. Thereby a capacitor plate is used as a plane active surface and the other as a surrounding cup. By approach of an object to the sensor surface, the dielectric and also the amount of capacity change. Contact-free recognition of electrically conducting and isolating bodies is the major advantage of such these sensors.

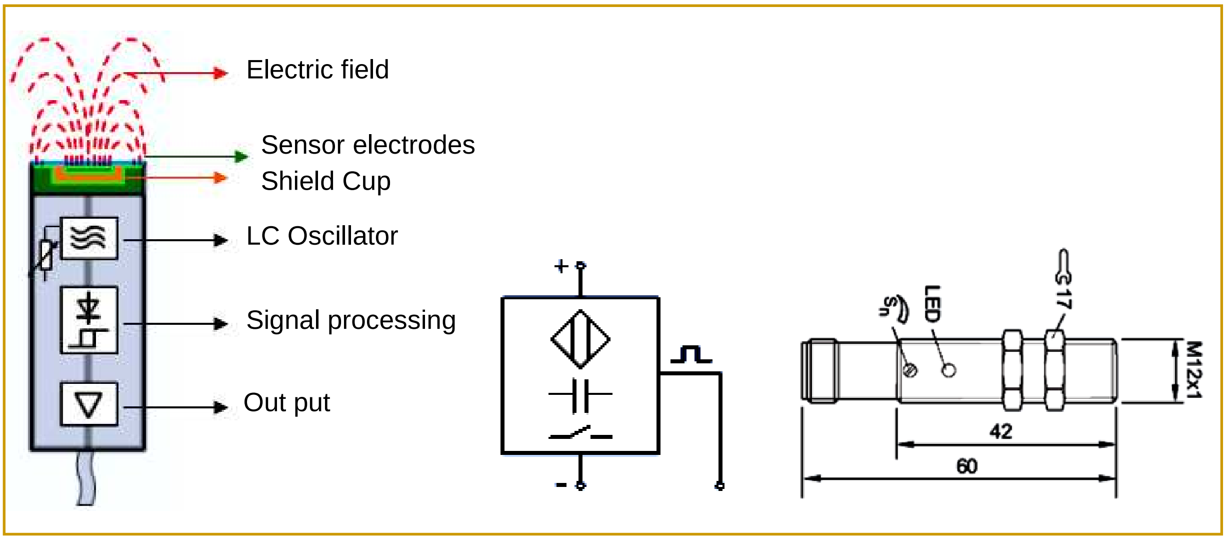


Figure 4-32: Capacitive proximity switch (electrical circuit and technical drawing).

4.14 Ultrasonic pickup sensor

Ultrasounds are the oscillations in a medium, e.g., air which lies between 20 kHz and 1 GHz (above the human hearing zone). Piezoelectric crystals are used as converters, which convert an electrical energy (voltage) into mechanical kinetic energy (transmitter).

Contact-free recognition of solid, liquid, powder and also transparent objects of the most different materials are the most important property of these sensors. Figure 4-33 illustrates the sending (a) and receiving (b) process of the impulses.

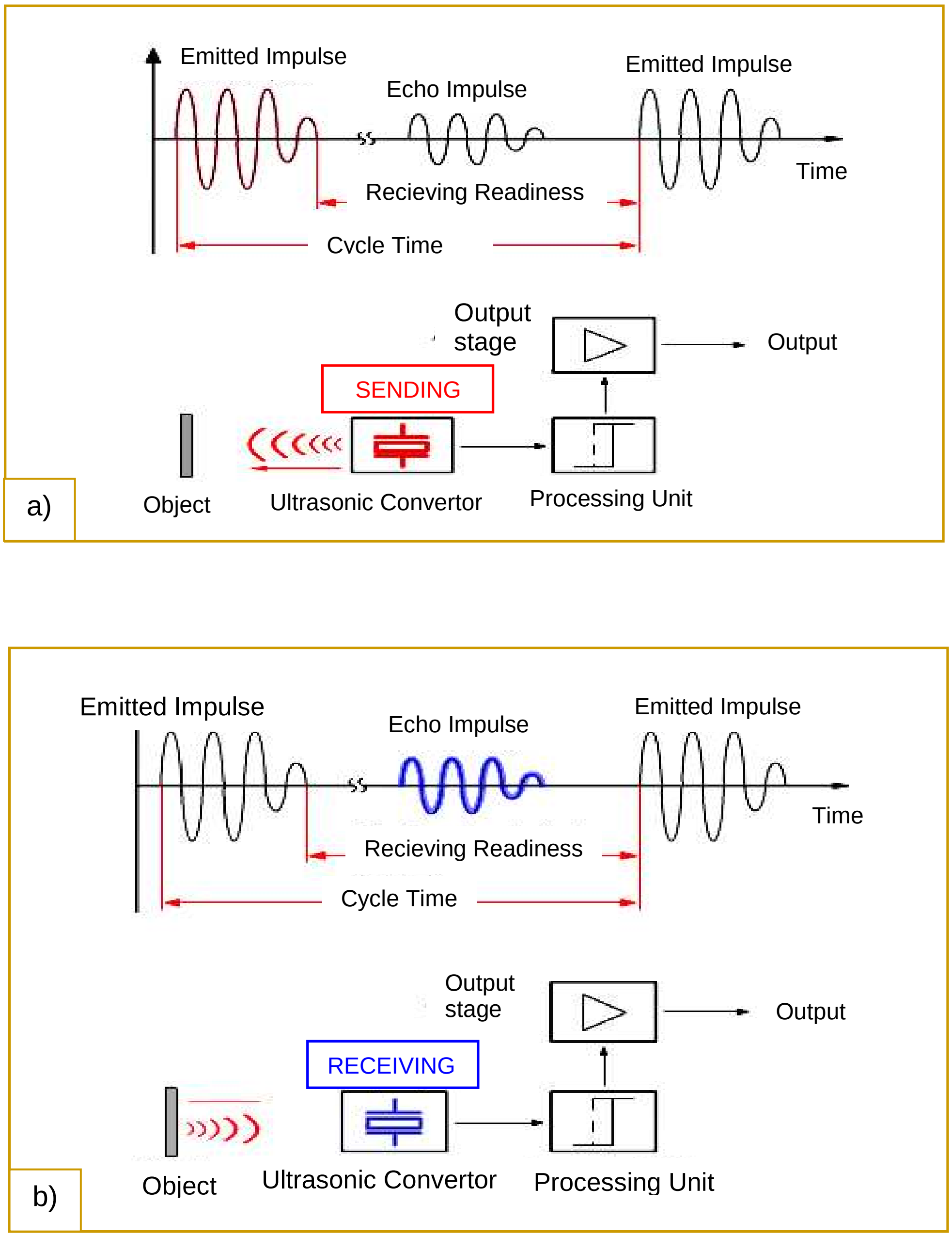


Figure 4-33: a) Ultrasonic sending signal b) Ultrasonic receiving signal.

4.14.1 Influencing parameters

Wavelength and propagation speed depend strongly on the medium in which the ultrasound spreads out. In water and metal the propagation is substantially bigger, than in the air. The propagation speed and also the measuring result depend also on the physical properties of the carrier medium (e.g., air temperature, atmospheric pressure).

One-head system actuation:

Transmitter and receiver are in one unit (Transceiver). This enables to make very compact sensors as shown in Figure 4-34. Working range: between 20 to 600 cm.

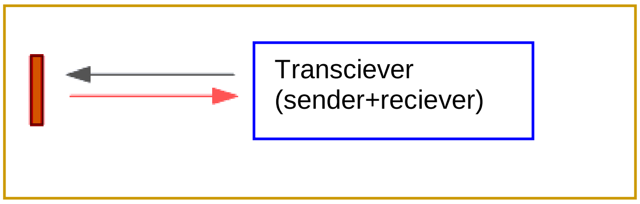


Figure 4-34: One-head system.

Two-head system actuation:

By the use of two separate Transducers (Figure 4-35), the working range can be considerably shortened, because only the response time of the receiver affects delaying. Both transducers can be installed in a unit housing or separately. Working range begins with 5 cm.

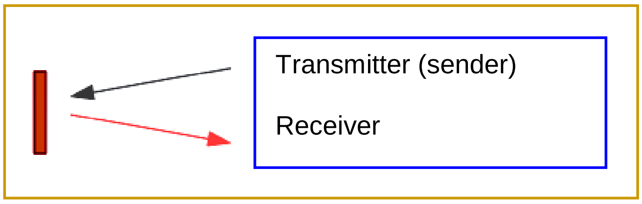


Figure 4-35: Two-head system.

One-way device in two head system:

In this system transmitter and receiver are confronted (Figure 4-36). Thereby the sound must put back the way between them only once.

Large coverage up to 15 m, increased interference resistance and high switching frequency are the advantages of the system.

Disadvantage: bigger assembly and installation expenditure.

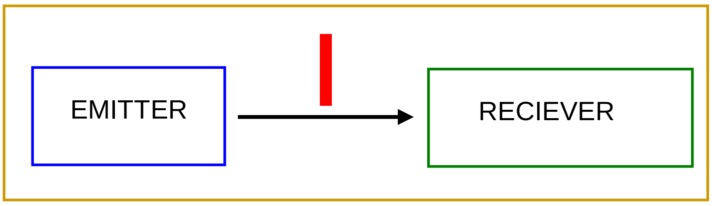


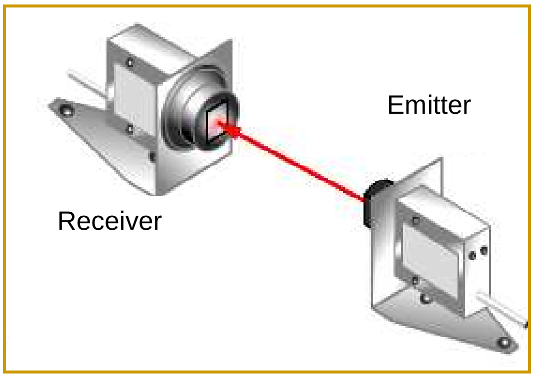
Figure 4-36: One-way device in two-head system.

4.15 Infrared sensors

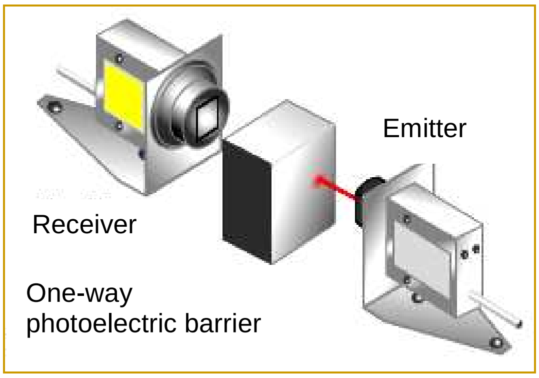
All optoelectronic sensors react to light intensity changes in the ray way between the transmitter and the receiver. Photo diodes and photo transistors are mostly used for the light transmitters LED's and for the receivers in the infrared sensors. The signal in these sensors is sent not as a continuous light, but in the form of light impulses, which raises the life span of the LED's with much lower continuous power rating . IR sensors can switch if they receive light (light-switching) or if they do not receive the light radiated from the transmitter (darkness-switching).

4.15.1 One-way photoelectric relay

Transmitter and receiver units are separated of each other. By interruption of the beam of light the receiver is switched (Figure 4-37 b). All not transparent and reflecting objects, up to very big distances (> 100m) can be thereby captured.



a)



b)

Figure 4-37: One-way photoelectric relay.

4.15.2 Reflection-photoelectric relay

Light is emitted by the transmitter and is thrown back by a firmly mounted reflector, practically completely, to the receiver. Transmitter and receiver are in one case as shown in Figure 4-38. All photo resist objects are likewise recognised. Problems can appear with shining surfaces if the sent out light of the object reflects exactly in the receiver from the object and not from the reflector.

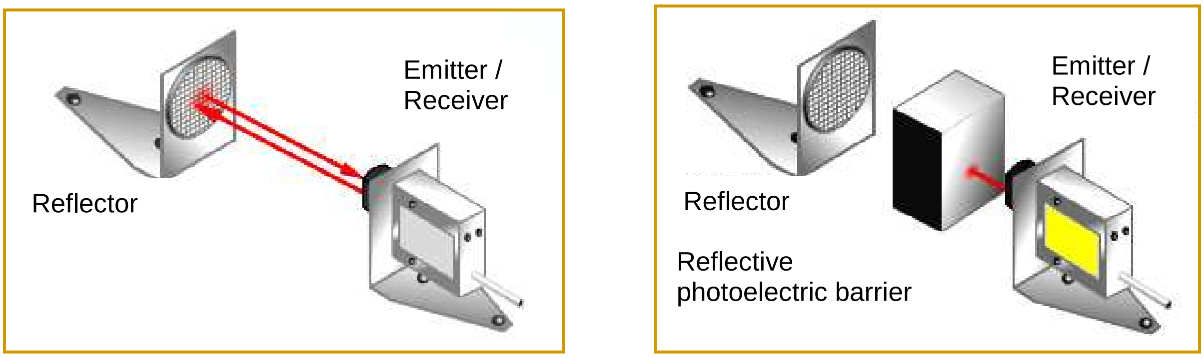


Figure 4-38: Reflection-photoelectric relay.

4.16 Frequency and position sensors

4.16.1 Contact-less digital tachometer

Frequency is the number of occurrences within a given time period. In a rotational speed frequency sensor the number of electric pulses during a time of one second will be measured. A counter counts the pulses, as shown in Figure 4-39, and a timer calculates the frequency and displays it every 1000 ms and start counting again from zero.

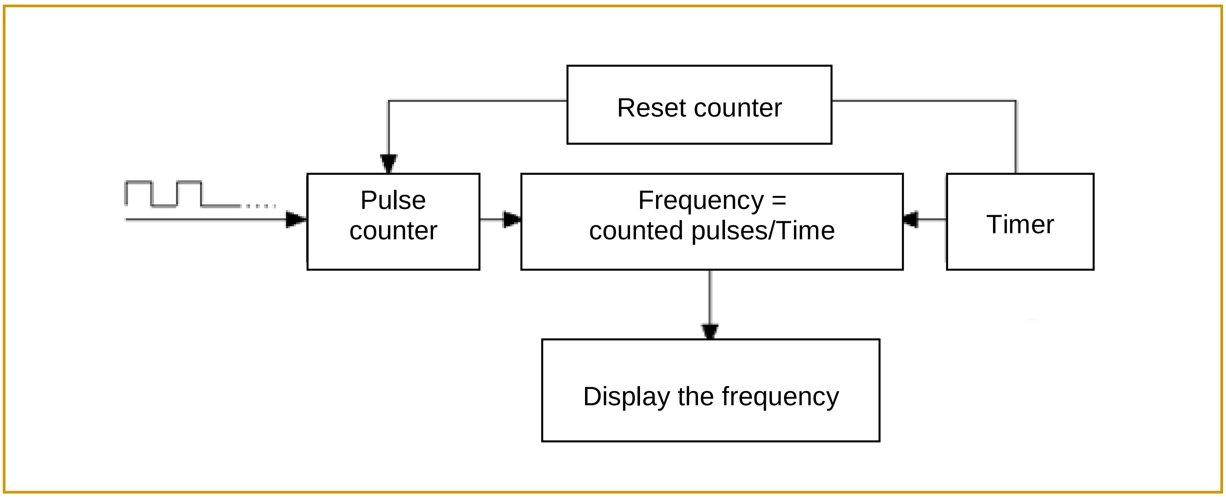


Figure 4-39: Block diagram of a digital frequency meter.

4.16.2 Pulse generation

4.16.2.1 Inductive (impulse sensor)

The inductive impulse sensor (Figure 4-40), is built up of a reel with iron core (ferromagnetic body). The iron wheel which moves near the reels / magnet arrangement builds a current change in the magnet circle and therefore generates an impulse-shaped induction voltage in the reel. The induced voltage becomes smaller with decreasing the rotational speed, so that in practice values less than 10 rotations per minute are not measurable any more.

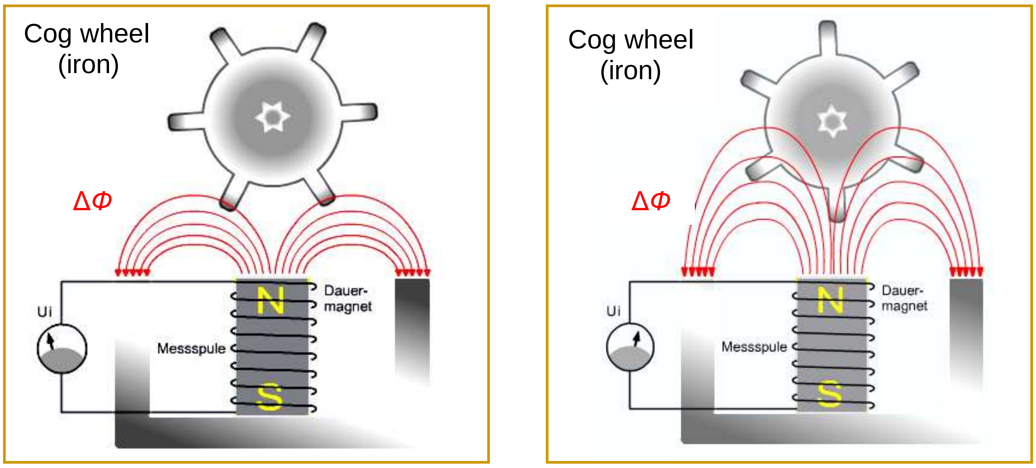


Figure 4-40: Inductive pulse generation.

4.16.2.2 Optical tachogenerators

In principle, these sensors work after the photoelectric relay or reflex light procedure (pls. see Infrared sensors 4.15). Therefore, the beam of light is interrupted, by a slit disc mounted on a shaft, which rotates between optical transmitter and receiver (Figure 4-41).

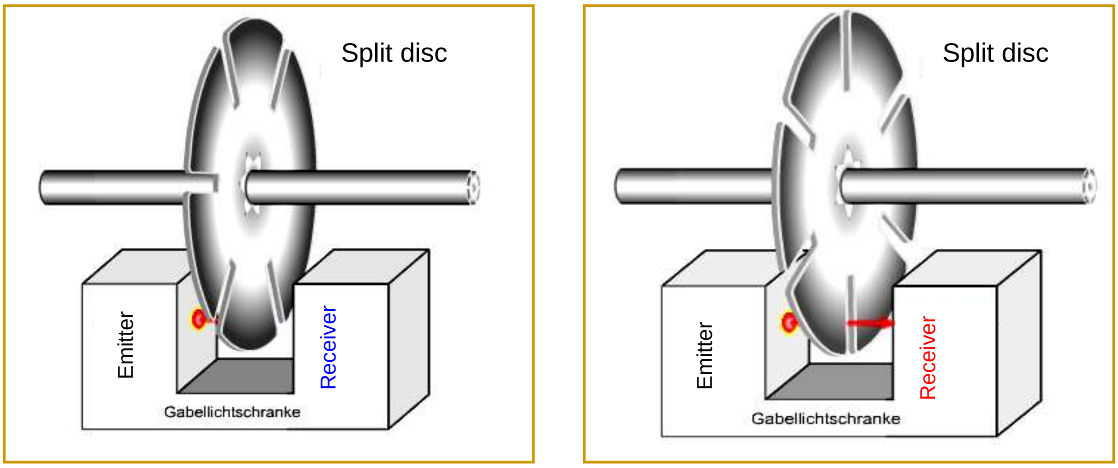


Figure 4-41: Optical tachogenerators.

4.16.2.3 Wiegand sensor

Certain ferromagnetic alloys (e.g. *Fe, Co, V,*) change immediately their magnetisation direction with appear of an external magnetic field (Wiegand effect). This rapid current change induces a voltage in the sensor reel which can be evaluated. A setting magnet produces the magnetic initial state again as shown in Figure 4-42.

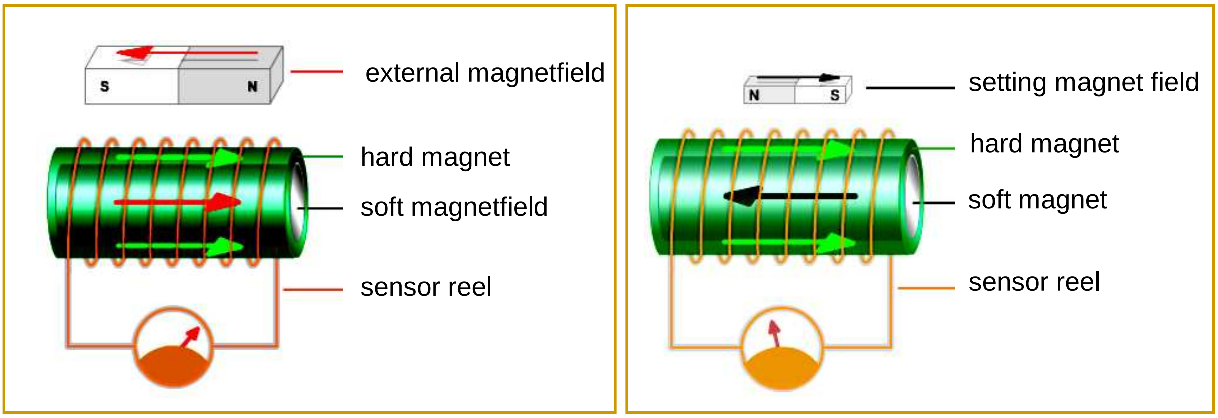


Figure 4-42: Wiegand sensor (impulse wire).

4.17 Disturbances by electrical sensors

Disturbances by electric sensors are mostly caused from the installation (e.g., flush installation). All electric sensors can be disturbed by disturbances (e.g. external magnetic field near a magnetic field sensor). Disturbances can be coupled in different ways. The most usual couplings are the galvanic, the inductive as well as the capacitive couplings.

5. SENSORS FOR UNDERGROUND MACHINERY

5.1 GENERAL

Nowadays different kinds of sensors are used in the field of underground machinery (Figure 5-1) for the purpose of increasing the accuracy, safety, operating efficiency and decreasing the troubles during the operation and eventually lowering the costs. In this chapter, details of the sensorics for two machines namely AVSA (Alternative Tunnelling System Cutting and Anchoring) and ATM (Alpine Tunnelling Machine) will be discussed.

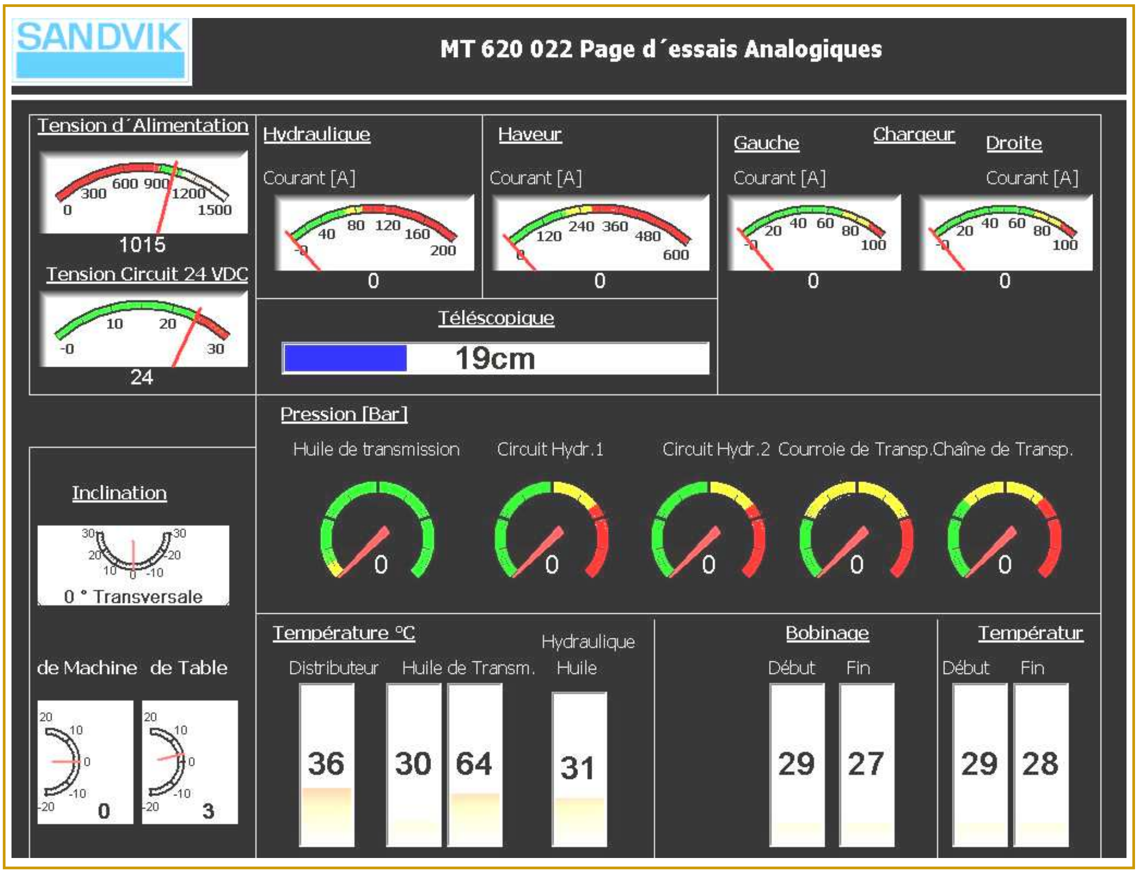
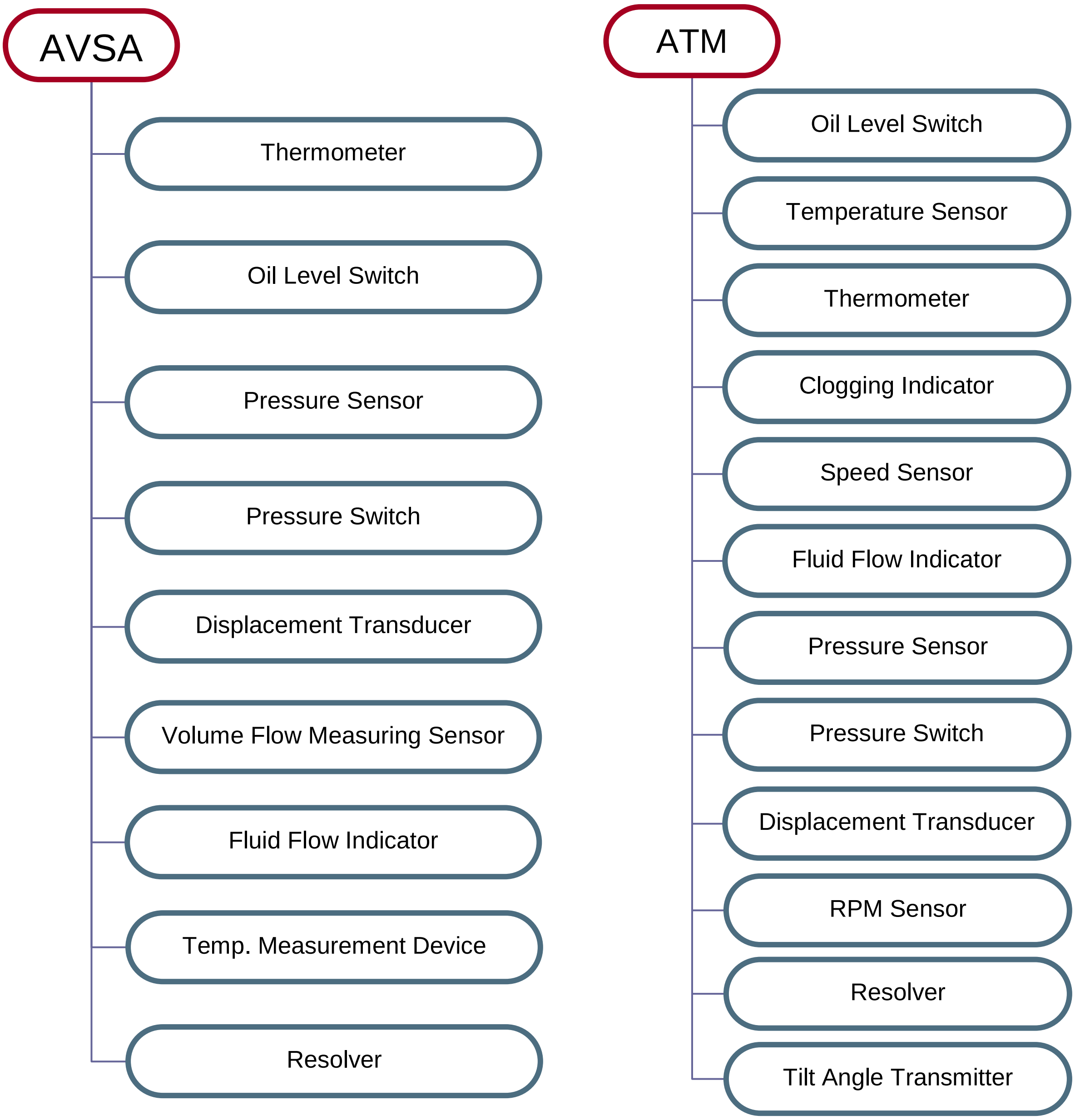


Figure 5-1: Sensor monitoring for underground machinery

5.2 SENSOR GENERAL VIEW

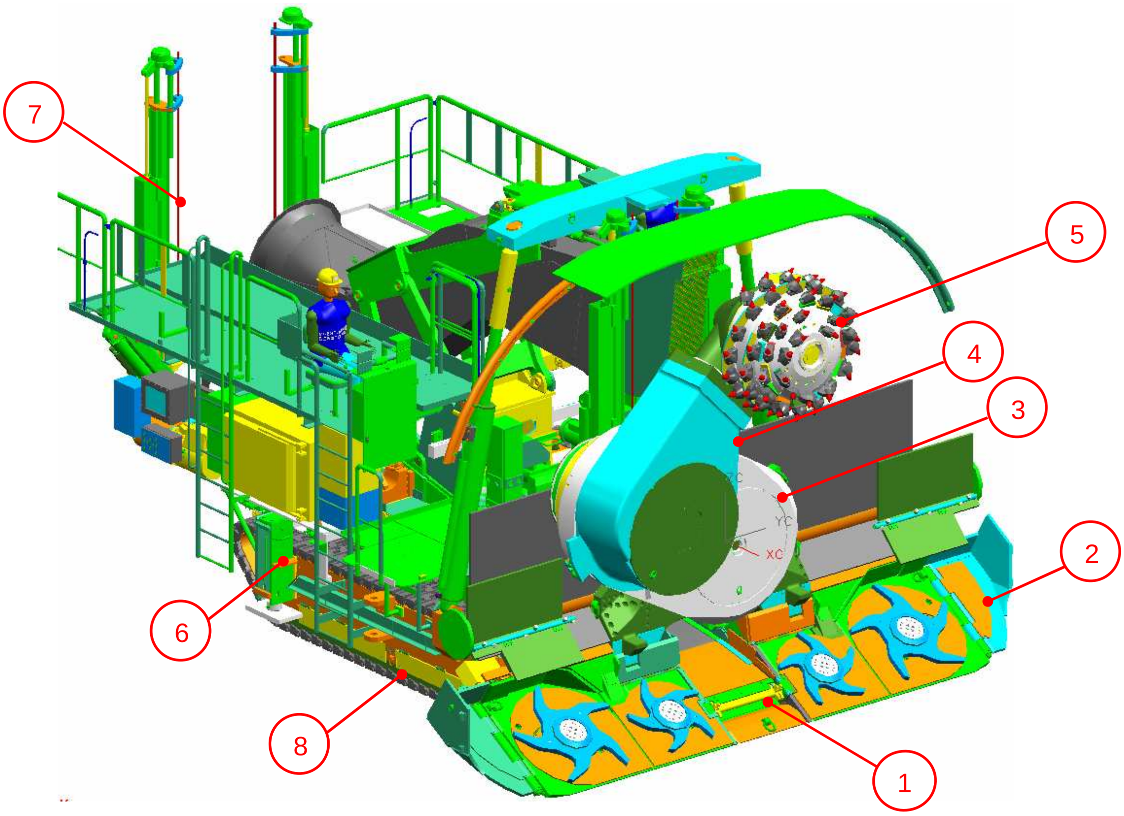


5.3 ALTERNATIVE TUNNELING SYSTEM CUTTING & BOLTERING

5.3.1 General

The AVSA (Figure 5-2) is basically a continuous tunnelling system. Two bolter rig stations are integrated into the machine. All drilling equipment are located immediately behind the cutting unit, which enable it to work more safely and with a larger efficiency in tunnels and mines with soft rock.

The new design (for the first time in the year 2000 for a project in Germany) allows concurrent cutting and boltering; dust suppression and spraying system optimise the working conditions for the persons on site.



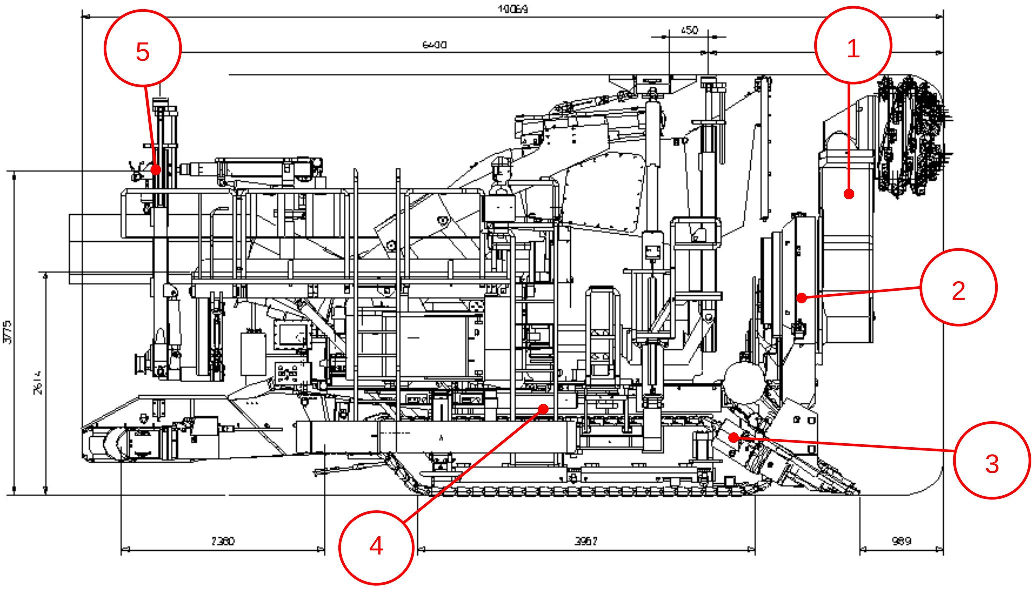
1	Conveyor front part	5	Cutter head
2	Loader apron	6	Stabilizer
3	Swinging arm	7	Bolter rig
4	Cutting arm	8	Crawler track

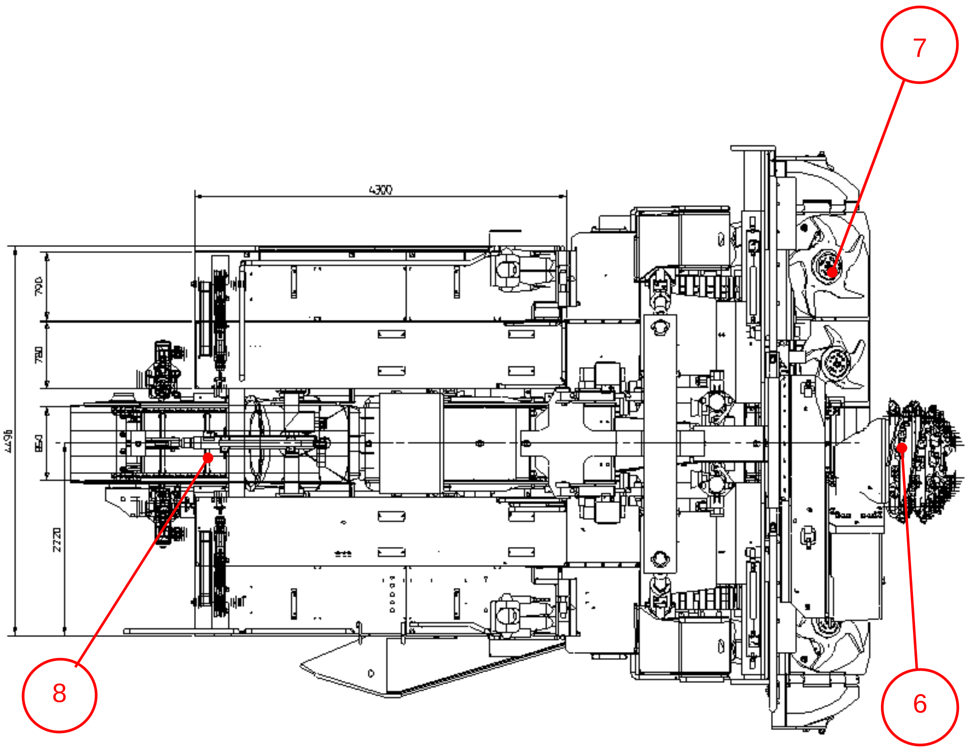
Figure 5-2: AVSA 3D-Illustration.

Some advantages of the AVSA which distinguish it from other machines with high mining capacity:

- Concurrent cutting and boltering
- Integrated high pressure spray system
- Low rotating speed of the cutting head to reducing dust development
- Bolter rigs mounted on the machine
- Loading device and conveyor device move together with the cutting unit
- Electronically steered break-in and disassembly movement to optimise the cutting function and the operation of the cutting engine
- Radio control for all functions with the exception of the drilling function
- Cutter head with interior nozzle
- Completely automatic lubrication system with low servicing requirements

5.3.2 AVSA Sensor Positioning





1	Cutter arm revolver	5	Bolter rig pressure sensor
2	Swinging arm revolver	6	Cutter head gearbox temperature transducer
3	Lineal displacement (apron)	7	Spinner motor overload sensor (PT100)
4	Lineal displacement (sump slide)	8	Conveyor speed sensor

Figure 5-3: AVSA Sensor positioning a) side view b) top view.

5.3.3 CONTROL SYSTEM

The sensors which are used in the control system determine the position of the cutting- and swinging arm bolter rig platform, sump slide and apron.

5.3.3.1 Revolver (Position Sensor)

This sensor (Figure 5-4) measures the position of the cutter boom and the swinging arm with the measuring range between 0 to 360°.

Figure 5-4: Position Sensor.

5.3.3.2 Position of Bolter Rig Platform Proximity Switches

These two sensors or proximity switches (Figure 5-5) are located on both sides of the machine and are used for checking the current position of bolter rig platform. If the bolter rig platform is in "park position", a 12 V signal will be sent to the control system from the proximity switch.

Figure 5-5: Position of bolter rig platform proximity switch.

5.3.3.3 Displacement Transducer

The contact-free displacement transducer works with a linear resolution of 2 mm above the whole measuring area. This sensor has an integrated reverse voltage protection mechanism as well as a voltage stabilisation device (with a help of an operation amplifier). The displacement transducer is located on the loading table cylinder as shown in Figure 5-6 and on sump slide hydraulic cylinders (Figure 5-7) at both sides of the machine.
Output signal is 4 to 20 mA, the nominal supply voltage is 12 V DC.

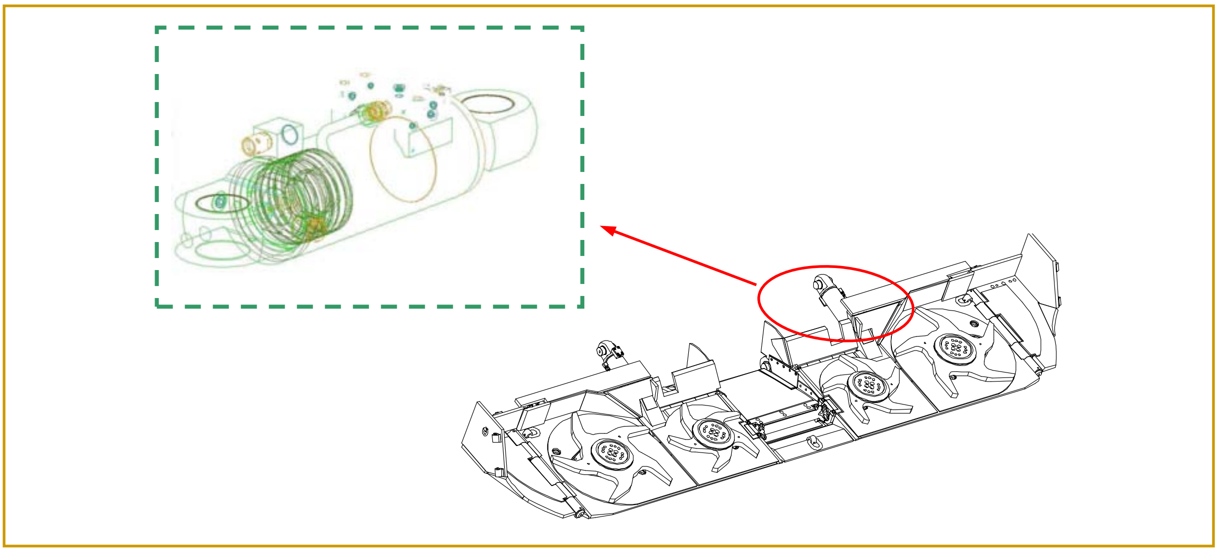


Figure 5-6: Apron hydraulic cylinder for raising and lowering the loading table.

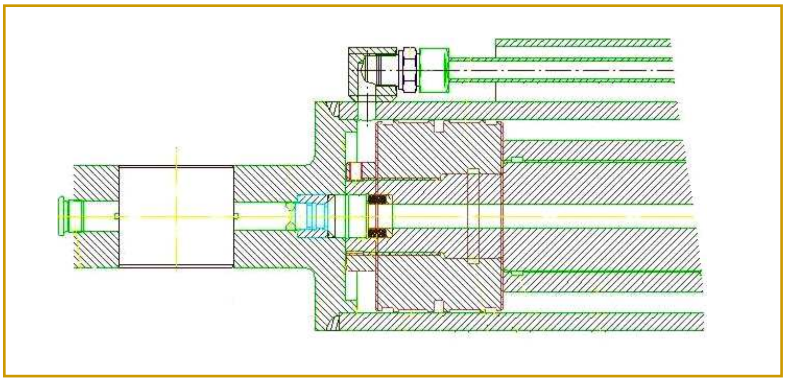


Figure 5-7: Sump slide hydraulic cylinder at both sides of the machine.

5.3.4 HYDRAULIC SYSTEM

The sensors which are used in the hydraulic system are responsible for measuring the pressure and the temperature of the medium in high-pressure and return pipes and devices and indicate the values or transfer them to an indicator. Additionally an oil-level sensor is used in the tank.

5.3.4.1 Differential Pressure Switch (Clogging indicator)

This sensor (Figure 5-8) is used to check the hydraulic system to prevent clogging of the pipes because of dirt and particles in the oil or to indicate the oil which is too viscous. The analogue optic indicator has a range of three colours: green, yellow and red.

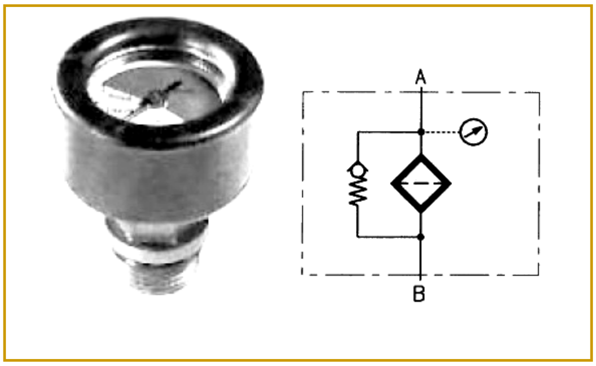


Figure 5-8: Clogging indicator with diaphragm.

5.3.4.2 Pressure Measuring Device

This sensor, as shown in Figure 5-9, is responsible to capture the present pressure of the hydraulic system with a working range of 0 - 400 bar and a maximum pressure of 1000 bar. The output signal of this sensor varies from 4 to 20 mA, depending on the pressure; the signals pass through a two-wire circuit to the measuring device.

Functioning Principle:

A piezoresistive or capacitive pressure transducer generates an electrical current if too high pressure occurs.

Supply voltage and amperage: 9 - 30 V DC, 100 mA

Figure 5-9: Pressure measuring device with and without LCD.

5.3.4.3 Oil Level Switch

"The oil level sensor (Figure 5-10), is used to control the oil level in the hydraulic tank. In addition to the two contacts in the device, there is another contact for temperature cut out. However, this temperature switch is not used in this application.

The pre-warn contact, which is a shutter, gives a signal when the oil level is 270 mm under the filler opening, and the second contact is an opener which will be activated when the oil level is 360 mm under the filler piece [15]".

Figure 5-10: Oil level switch (L) and its position at the top of the hydraulic tank (R).

Function:

"The level is measured on the basis of the magnet switch principle. One or a number of reed contacts are arranged on a mounting rail. A permanent magnet passes and causes the contact to open or close. The level switch is normally equipped with two latching type contacts, with the upper contact designed as normally open contact for the alert function and the lower contact as normally closed contact for the stop function. The latching-type contact has storage characteristics. To this end, the reed contact is magnetically "pre-tensioned" in the two switching positions by two holding magnets. By means of the stronger switching magnet the switch can be set or reset.

It is also possible to use pulse switches for level monitoring. The contacts can further be connected with diode or resistor combinations for line monitoring. When continuous level monitoring is required, the level and temperature switch can be equipped with a chain of reed contacts with a spacing of 4 mm or 2 mm. The output signal would be provided by a voltage, current or frequency interface. These special cases will be available upon request. For temperature monitoring one or a number of thermal contact cartridges can be attached to the mounting rail at the lower end of the immersion pipe. These are normally open or normally closed contacts. It is also possible to use a PT100 element for continuous temperature measurements. The mounting rail with the level contacts and the thermal contact cartridges is housed in an immersion pipe which is enclosed by a float in the form of an annular magnet. This switching magnet is shielded against turbulences which might occur in the fluid by a smoothing pipe. Upon request, the level and temperature switch can also be supplied without smoothing pipe [16]".

5.3.4.4 Thermometer

The resistance thermometer (PT100), as shown in Figure 5-11, is a bolt sensor with a cable. The measuring signal goes via two cables (which are approximately 3 to 5 m long) to the temperature measurement device.
Maximum measuring range: 250 ℃

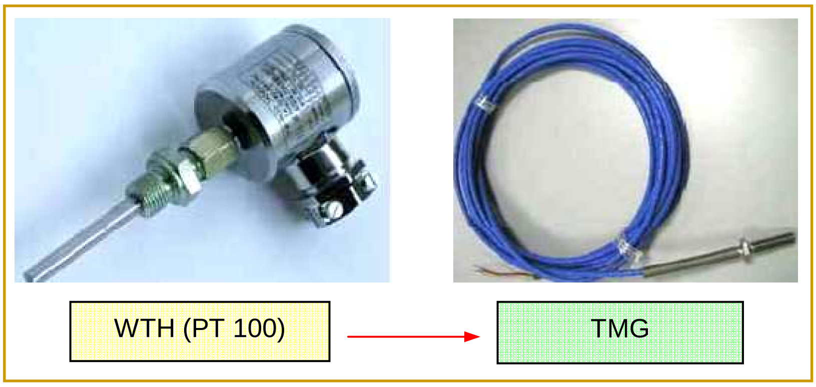


Figure 5-11: WTH with and without temperature measuring device.

5.3.4.5 Temperature Measurement Device

A resistance temperature detector (Figure 5-12), responds to temperature change in electric resistivity. The device works with an 8 to 16 DC supply voltage and gives an out put of a live signal between 4…20 mA in proportion to the measured value.

Figure 5-12: Temperature measurement device.

5.3.5 COOLING AND SPRAYING SYSTEM

The cooling and spraying system (Figure 5-13), is divided into two groups, water spraying and air spraying. These are used for dust suppression purposes and cooling the picks on the cutter head as well as diluting the methane gas at the site.
The sensors in the cooling and spraying system measure the water and air pressure inside the cutter head and also control and measure the water flowing in the system.

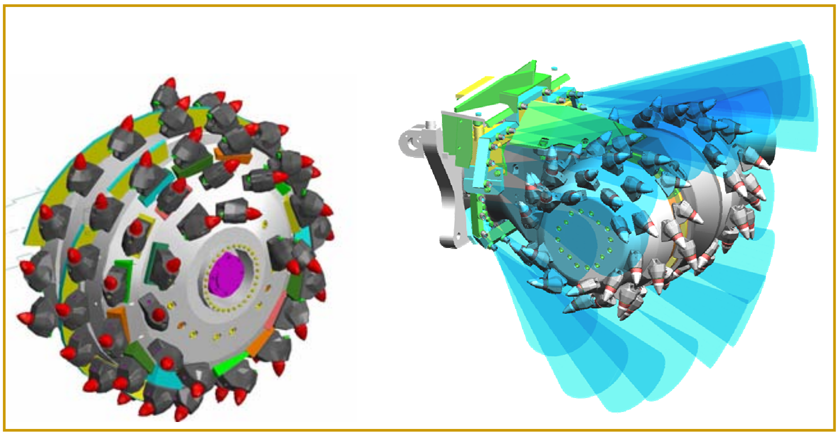


Figure 5-13: Spraying system on the cutter head.

5.3.5.1 Pressure air spraying diagram

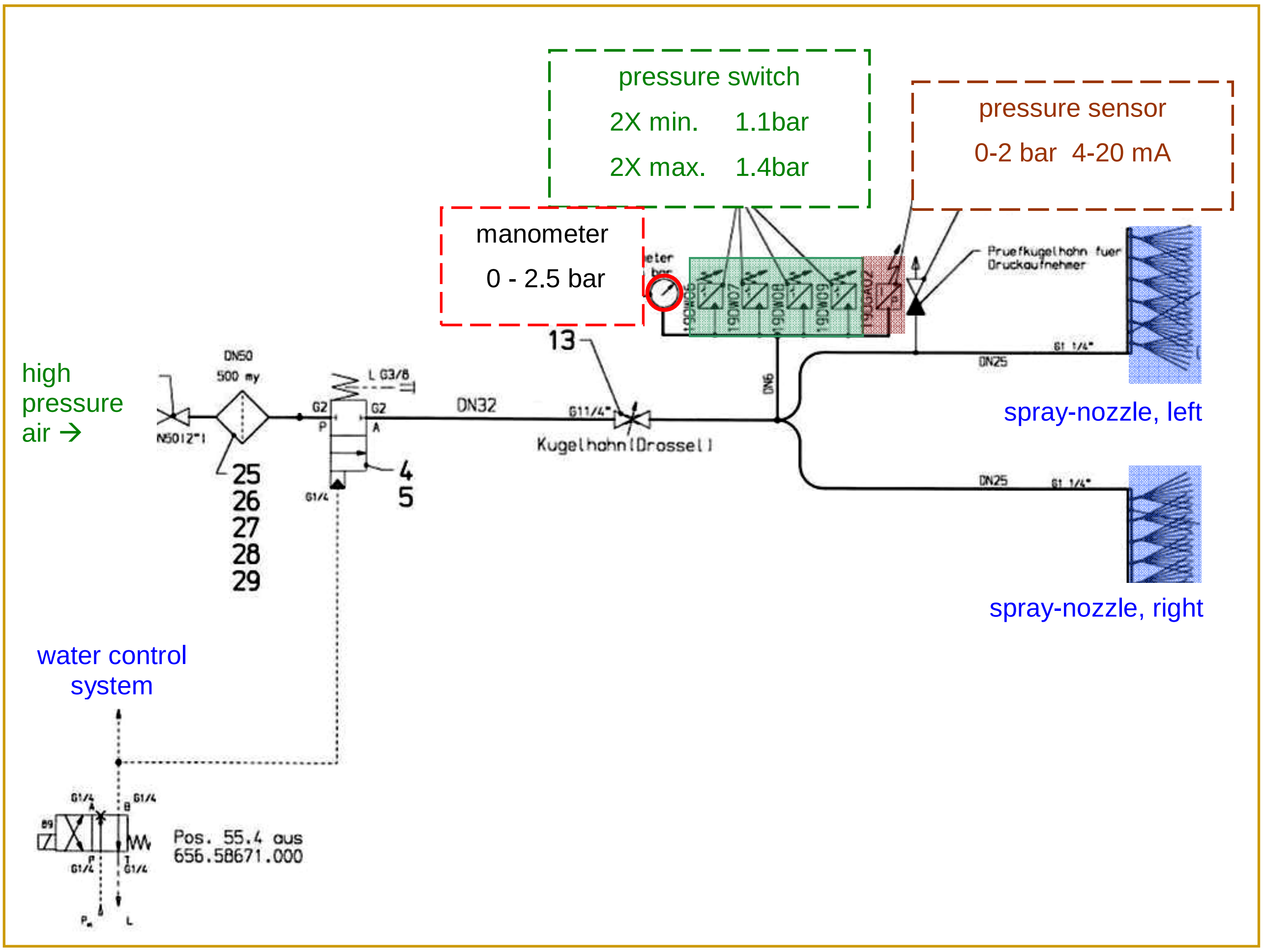


Figure 5-14: Pressure air spraying diagram; AVSA.

5.3.5.1.1 Pressure sensor

The pressure sensor (Figure 5-15), works in the range of 0 – 2 bar. The current supply is via a 3 m long cable with an output signal of 4 – 20 mA. The medium to be measured is water or air. The supply power of the sensor is between 8 – 16 V DC.

Figure 5-15: Pressure sensor 0-2 bar.

5.3.5.1.2 Pressure switch

This switch is used for controlling the air pressure with a digital out put signal. The pressure switch works in a range of 0.2…2 bar with a switching point of 0.8 bar.

Max. hysteresis: 0.1 bar

5.3.5.2 Cooling and spraying diagram

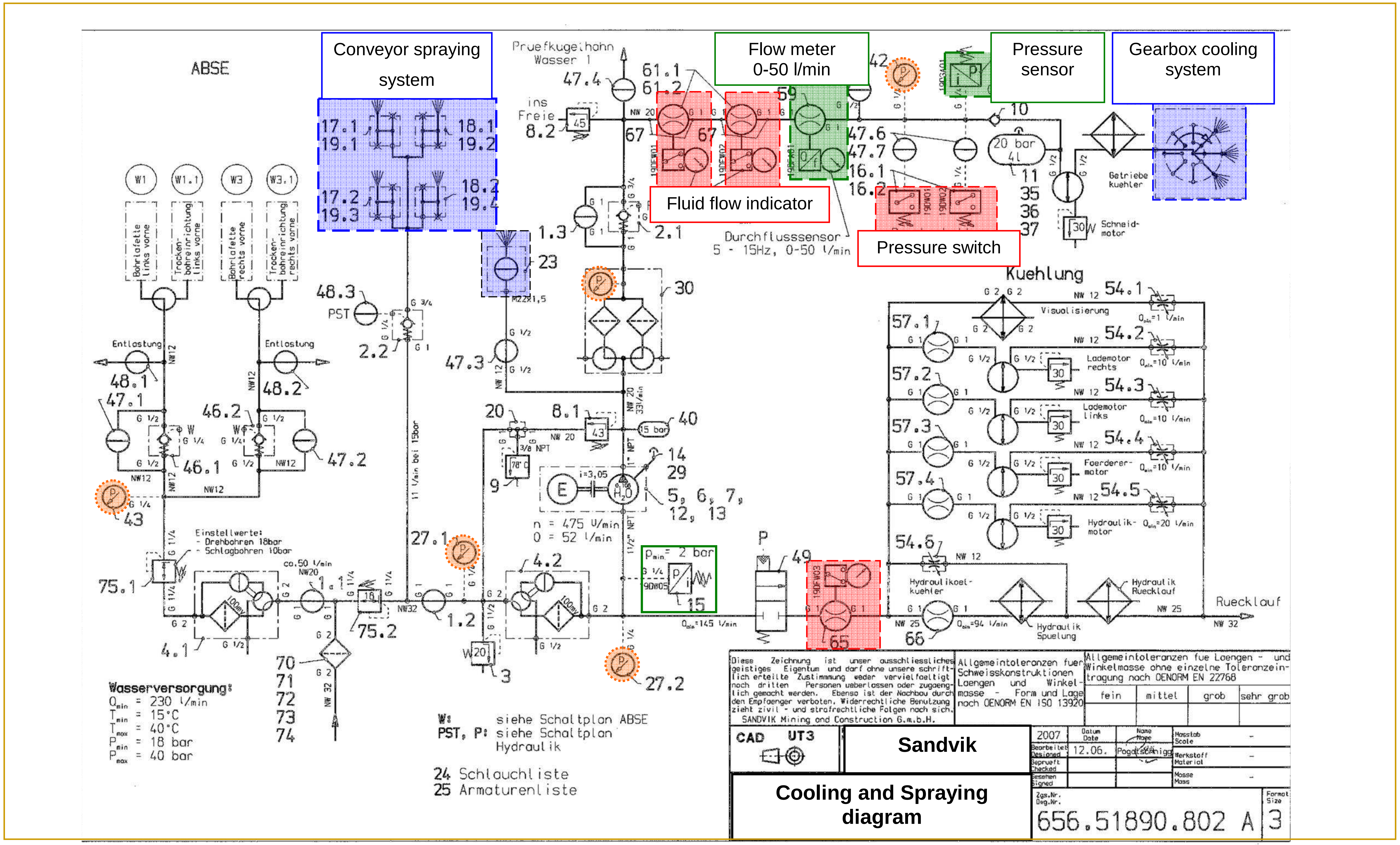


Figure 5-16: Cooling and spraying diagram; AVSA.

5.3.5.2.1 Pressure sensor

This pressure sensor (Figure 5-17), works in the range of 0 – 40 bar. It is equipped with LCD on site and has an output signal of 4 – 20 mA. The medium to be measured is water, oil or air with an accuracy of >1% up to 40 ℃. The worki ng temperature is between -20 to +60 ℃ and the supply power 8 – 30 V DC.

Figure 5-17: Pressure sensor 0-40 bar.

5.3.5.2.2 Pressure switch

This switch (Figure 5-18), is used for controlling the water pressure with a digital output signal. The pressure switch works in a range of 0. 22 to 4 bar for the upper switching point and 0. 07 to 3.75 bar for the lower switching point. The maximum working pressure is 24 bar. If the pressure of the spraying medium falls below this, the cutter motor will stop. The switch works with a 12 DC voltage and the operating temperature is between 20 ℃ and 70 ℃.

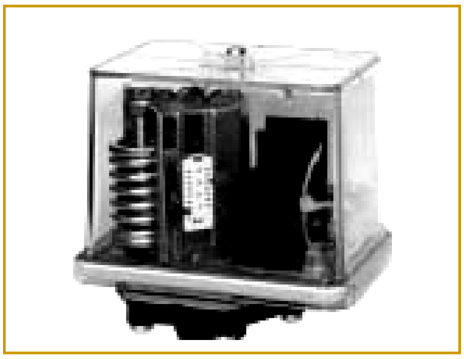


Figure 5-18: Water pressure switch.

5.3.5.2.3 Fluid Flow Indicator

The fluid flow indicator (Figure 5-19), indicates the amount of medium (oil or water) in the cooling and spraying system. There are two indicators, one for only water and the other for water or oil.

The working ranges of the indicators are:

- 0-50 l/min (water or oil)
- 0-200 l/min (water)

Figure 5-19: Fluid flow indicator.

5.3.5.2.4 Fluid Flow Measuring Device

This fluid flow measuring device, as shown in Figure 5-20, which is equipped with an LCD, measures the amount of medium flowing through the nozzles (here the medium is only water). The sensor works with a 9 – 13 DC voltage and an output signal of 5 – 15 Hz. The measuring range is from 0 to 50 l/min.

Figure 5-20: Volume flow measuring device.

5.3.6 LOADING TABLE

Please refer to 5.4.4

Drive system: 2 X 36 kW

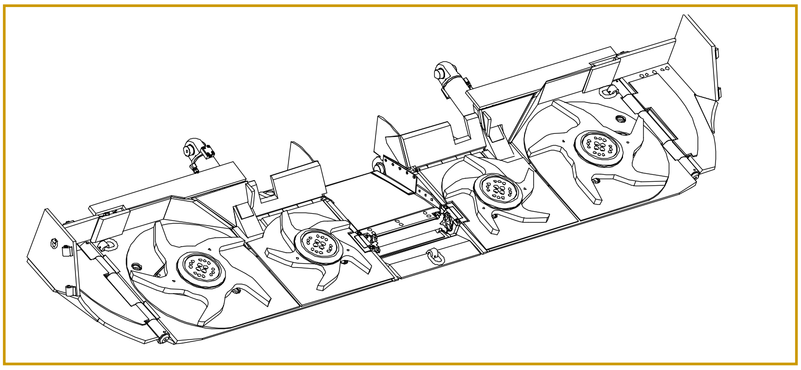


Figure 5-21: Loading table, AVSA.

5.3.7 BOLTER RIGS

Bolter rigs are designed for the purpose of drilling and bolting the top tunnel arc to prevent it falling. Pressure sensors are mounted on the bolter rigs to make sure that a minimum pressure is available for bolting purposes. There are two sensors on the front bolter rig (left and right) and two on the rear one.

Type: DMG/HOFI2SI 0 – 400 bar. Measuring range: 0 – 400 bar over loading to 600 bar.

Power supply: 8 – 16 V DC; Output: 4 – 20 mA

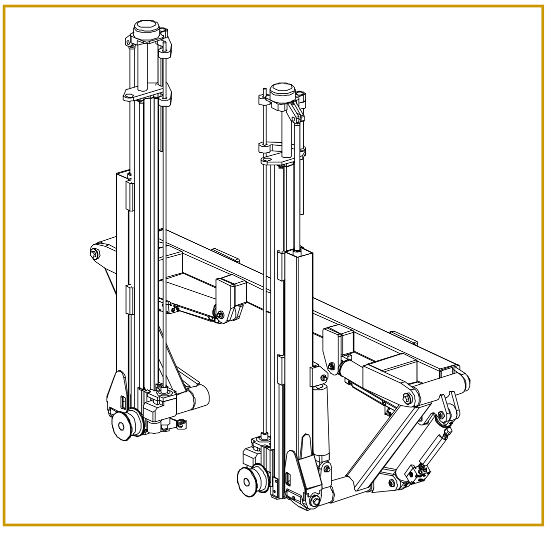
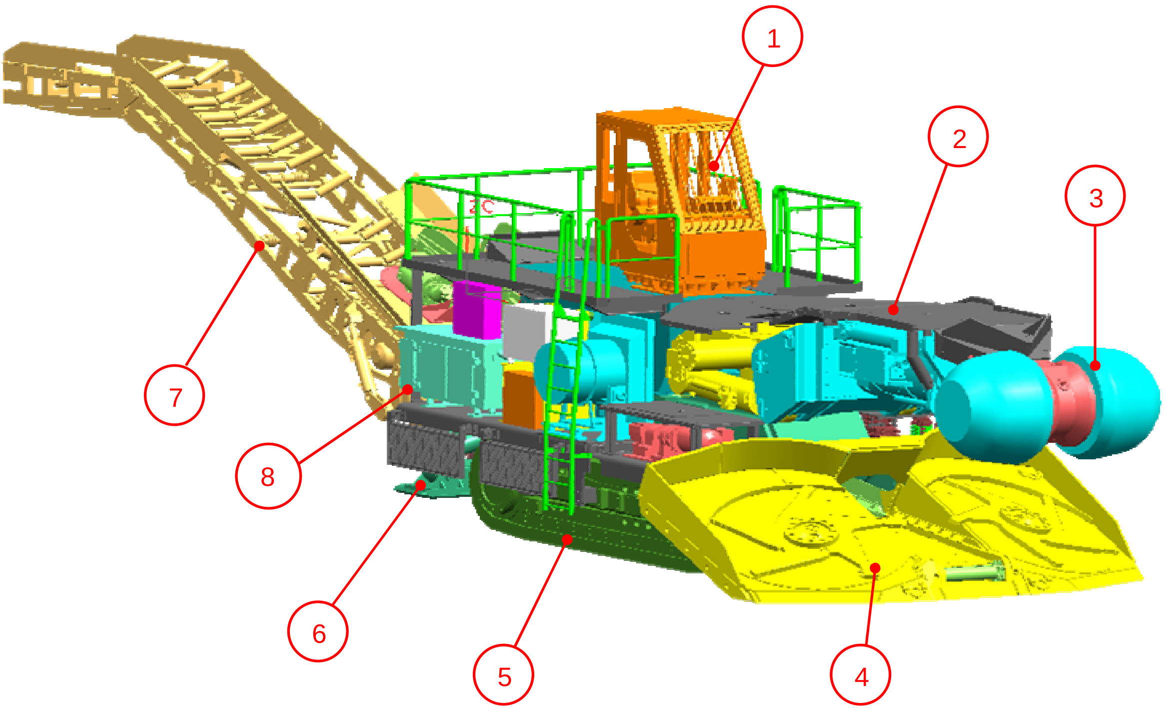


Figure 5-22: Bolter rig construction.

5.4 ALPINE TUNNELING MINER

5.4.1 General

Road headers, as shown in Figure 5-23, are excavating machines consisting of a boom-mounted cutting head, a loading device usually involving a conveyor and a crawler travelling track to move the entire machine forward into the rock face.



1	Operator's cabin
2	Cutter boom
3	Cutter head
4	Loading apron

5	Crawler track
6	Stabilizer
7	Swivel belt conveyor
8	Electrical equipment

Figure 5-23: ATM 3D-Illustration.

As any other industrial machine the safety and accuracy of the road headers are being developed. Therefore there will be more and more usage of different kinds of sensors. Road headers are used in tunneling both for mining and municipal government projects.

With the help of these sensors and their careful monitoring (Figure 5-24), the operator has a better oversight of the whole machine situation.

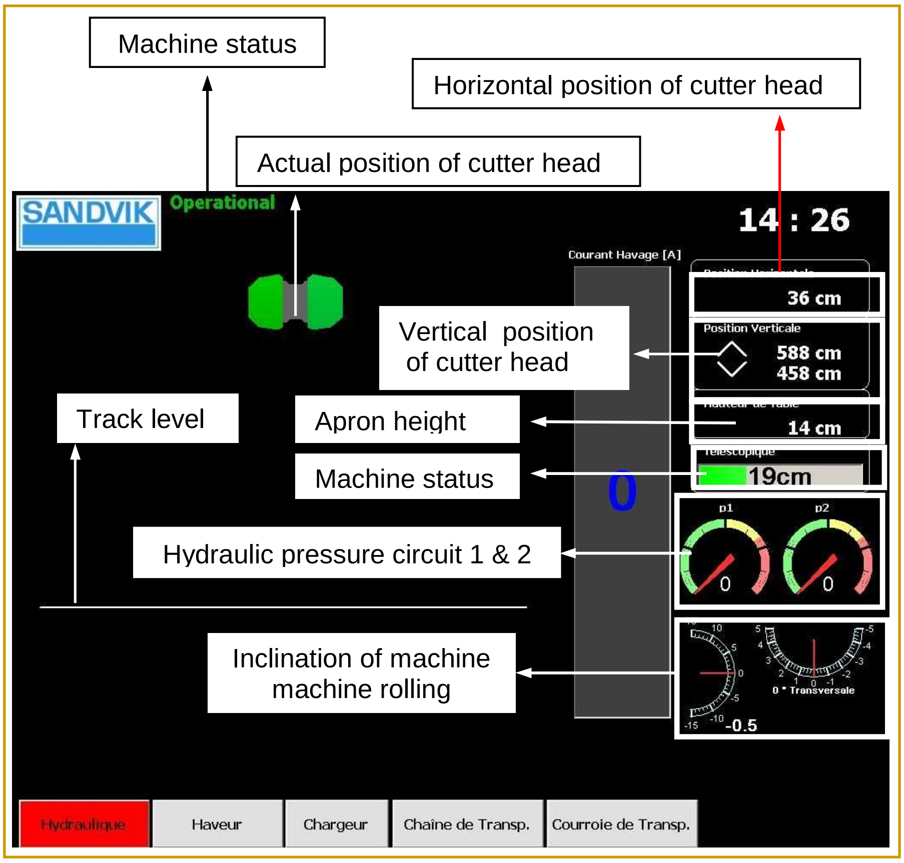
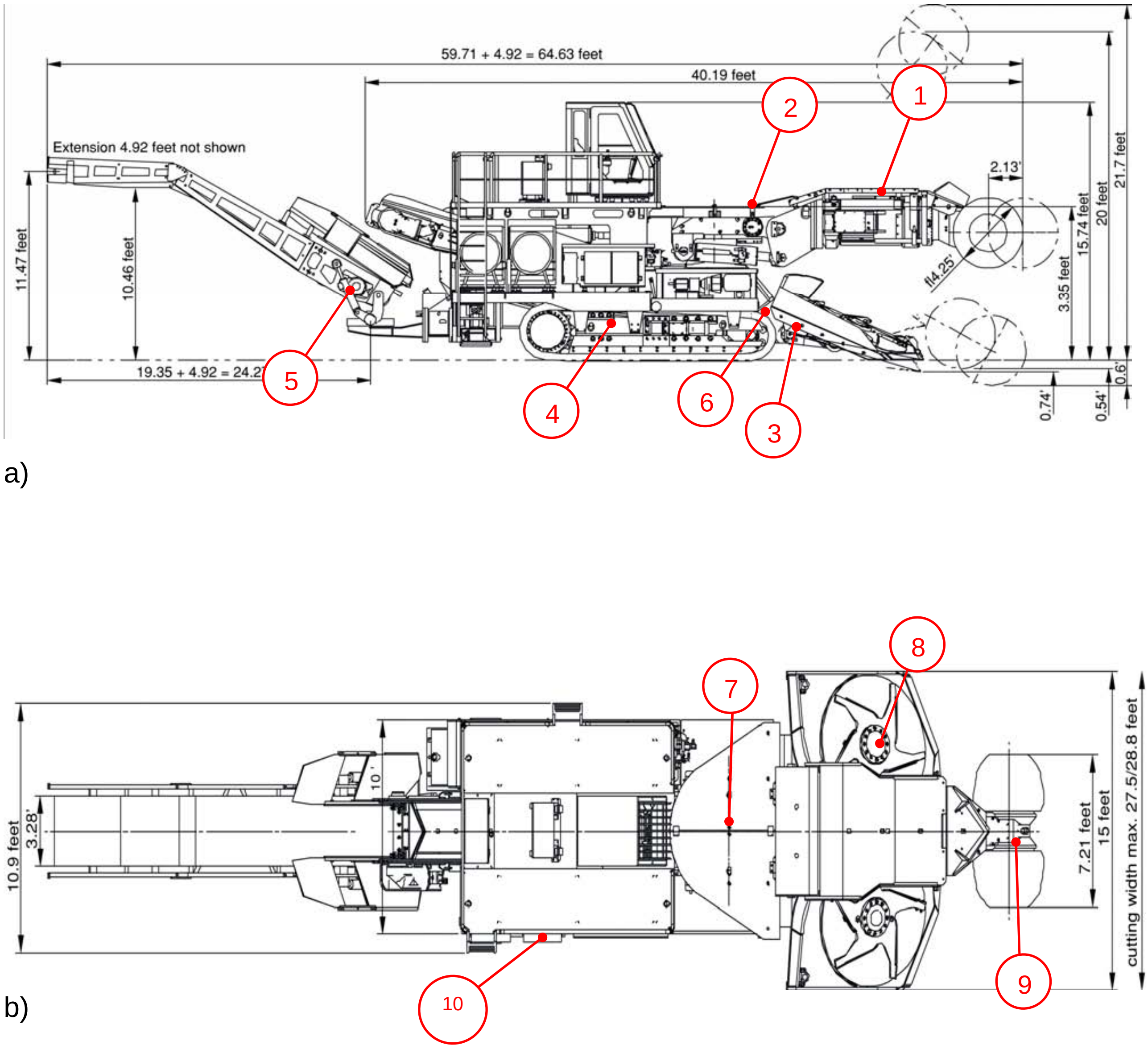


Figure 5-24: Operator display.

In this chapter the functionality of sensors on these machines will be explained.

5.4.2 ATM Sensor Positioning

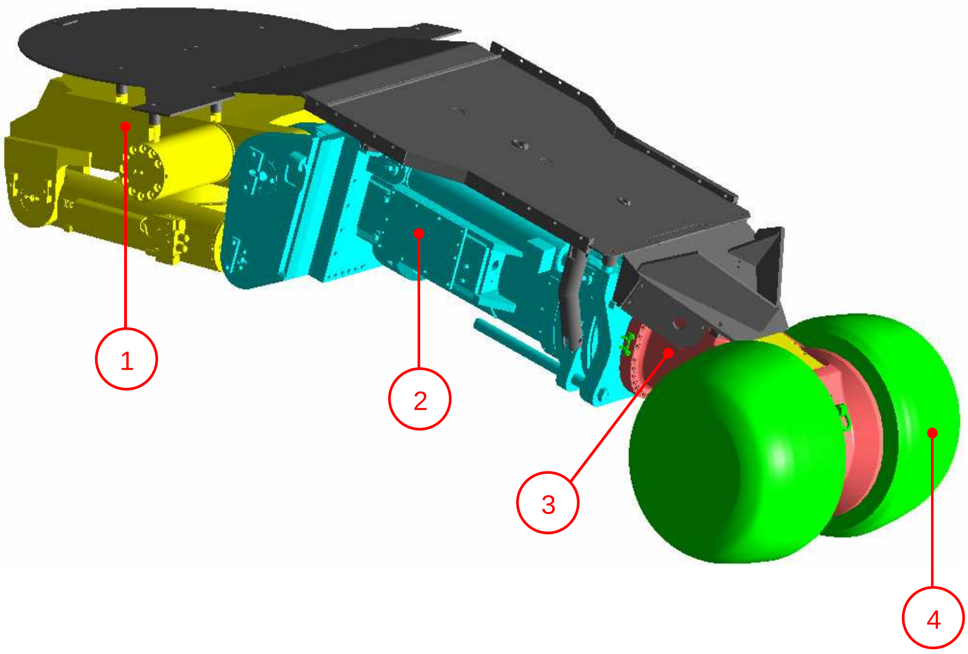


1	Telescopic boom displacement transducer	6	Apron cylinder displacement transducer
2	Inclinometer (vertical)	7	Inclinometer (horizontal)
3	Inclinometer (apron)	8	Spinner motor overload detection (PT 100)
4	Inclinometer (machine)	9	Gearbox oil temperature sensor
5	Conveyor belt speed sensor	10	Oil pressure indicators

Figure 5-25: ATM sensor positioning a) side view b) top view.

5.4.3 CUTTING SYSTEM

The cutting process is carried out in two different ways, depending on the purpose. The 3D-illustration of the cutting system components (Figure 5-26) consisting of a turret, telescopic boom, cutter gearbox and cutter head which will be discussed below, focussing on the sensors mounted on these devices, as well as their operation and their problems.



1	Turret	3	Cutter gearbox
2	Telescopic boom	4	Cutter head

Figure 5-26: Cutting system 3D-Illustration.

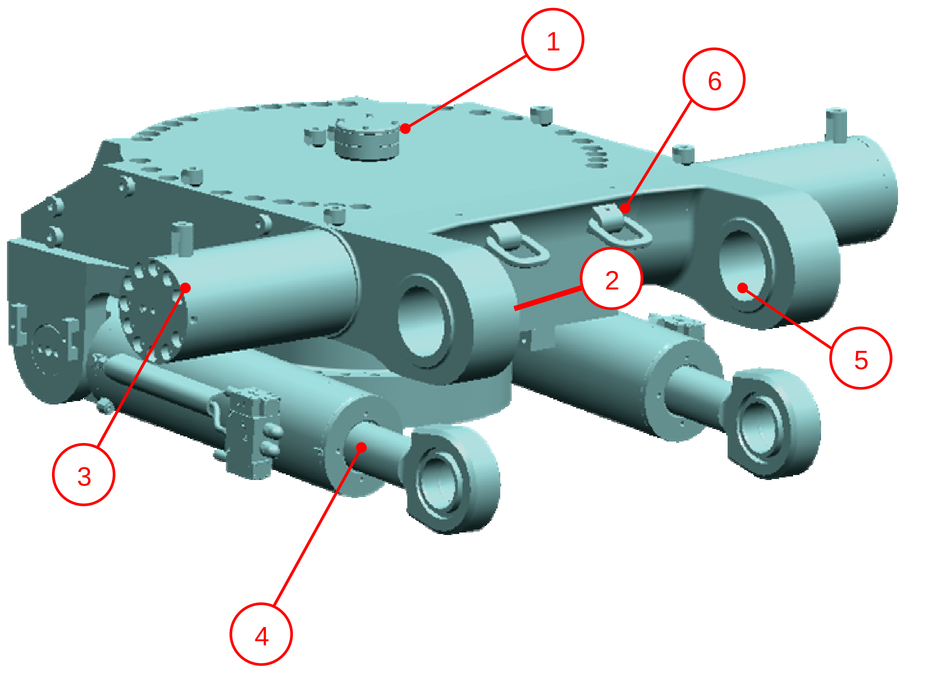
There are two different cutting modes for different purposes:

Manual cutting mode: for cleaning edges and maintenance purposes.

Automatic cutting mode: this is the default operation mode. This mode has several advantages to increase production as well as protect the cutter motor against overloads.

5.4.3.1 Turret

The turret (Figure 5-27), which is linked to the frame, makes vertical and horizontal boom movements possible and provides a constant horizontal slewing speed with the help of a rack and pinion system. It also absorbs the vibrations via the disc support ring. Horizontal pivoting (approx. 37° each to right and left) is ac hieved with the aid of two hydraulic cylinders. Vertical pivoting (approx. 73°) is achieved with th e aid of two hydraulic cylinders, which are attached to the motor support and the turret.



1	Horizontal inclinometer	4	Vertical pivot cylinder
2	Vertical inclinometer	5	Bearing cutter boom
3	Horizontal pivot cylinder	6	Ring trestle (lifting lugs)

Figure 5-27: Turret 3D-Illustration.

5.4.3.2 Cutter Boom (Telescopic Boom)

The cutter boom as shown in Figure 5-28 provides the longitudinal stroke of the cutter head (ca. 650 mm) via hydraulic cylinders and includes an approx. 300 kW motor. The cutter boom has the following functions: raising, lowering, pivoting left and right, all of which are monitored by different sensors.

Figure 5-28: Telescopic boom.

5.4.3.2.1 Cutter Boom Position Sensor

The horizontal boom position is detected with the help of a rotary encoder. The encoder is equipped with multifunctional inputs which allow a setting of the zero position.
The output signal is between 4 ... 20 mA.

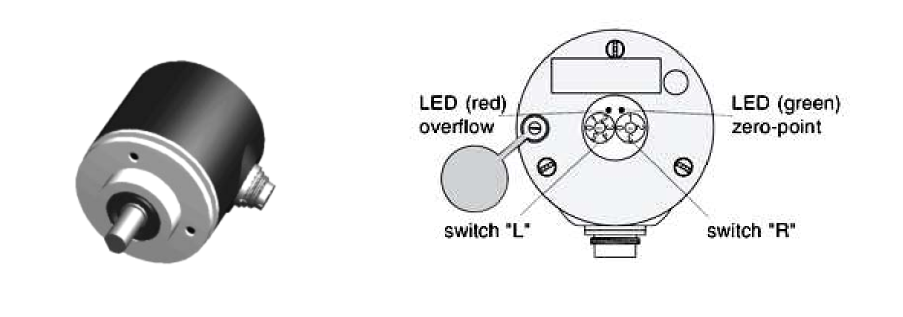


Figure 5-29: Cutter boom position sensor.

5.4.3.2.2 Lineal Displacement Transducer

The longitudinal direction of the cutter head is detected with a linear displacement transducer, shown in Figure 5-30. It is mounted on the cutter arm and has a measuring range of 0…700 mm with an output signal of 4 … 20 mA.

Function Principle:

“Path measurements are conducted on the basis of the magnet switch principle with inert gas contacts being strung together over the complete measuring length. The distance between the contacts which is the measure for the contact spacing is 2 mm or 4 mm. The individual contacts act on a combination of resistors.

The path over the measuring length is determined by means of a permanent magnet. The latter passes along the reed contacts and the respective contact activated provides a resistance value which will be evaluated to determine the position. A current or voltage output is available for the analog signal. Without additional connection the resistance value can be used direct for evaluation.

The chain of resistors with the reed contacts and the evaluation circuit is embedded in cast resin and housed in a rugged pipe made of stainless steel. This arrangement ensures adequate safety with respect to explosion protection and mechanical damage. The cable leading out of the potting compound largely resists acids and alkaline solutions. In order to enable the user to adapt to the conditions of application the output cable can be provided with free conductor ends or a Lumberg connector.

The permanent magnet comes in the shape of an annular magnet. The magnet segments are housed in a brass enclosure and are also embedded in cast resin compound [17]”.

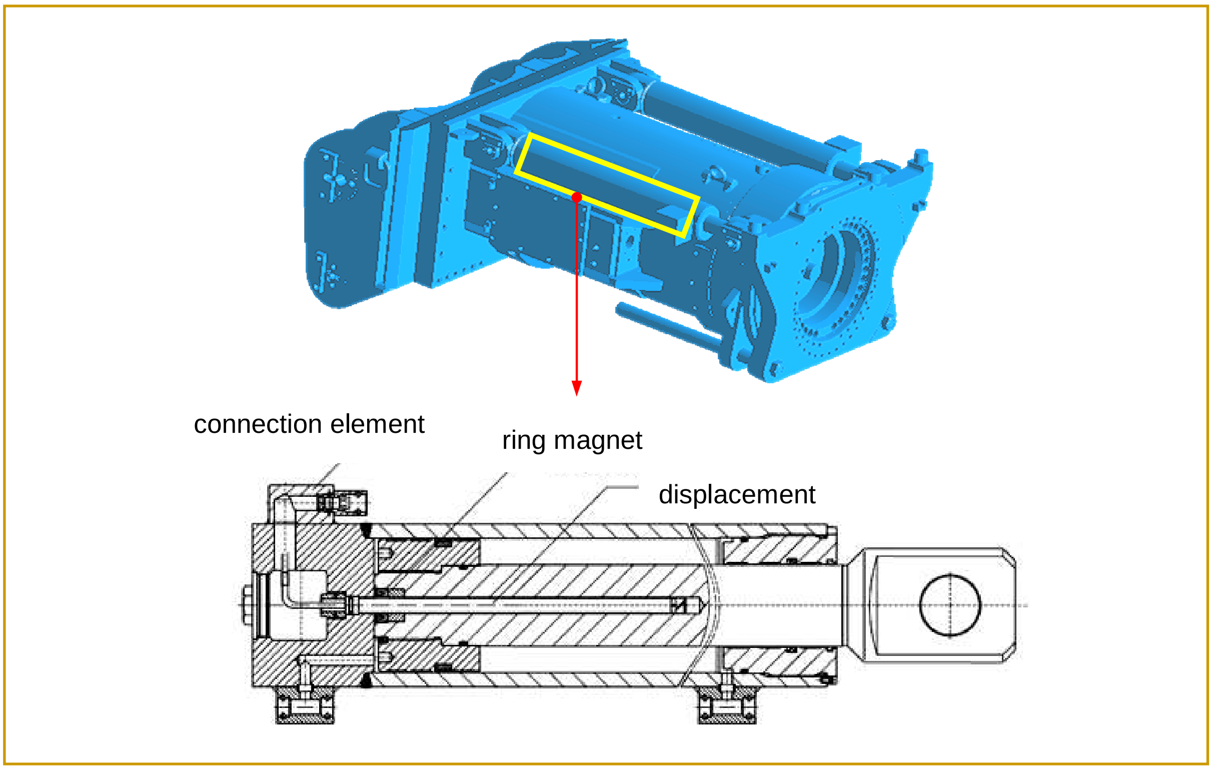


Figure 5-30: Lineal displacement transducer on telescopic boom.

5.4.3.3 Cutter head gearbox

The Cutter head gearbox (Figure 5-31) is mounted on the head of the telescopic boom and thereby transmits the speed and torque of the output shaft of the motor with a direction change of 90° to the cutter head.

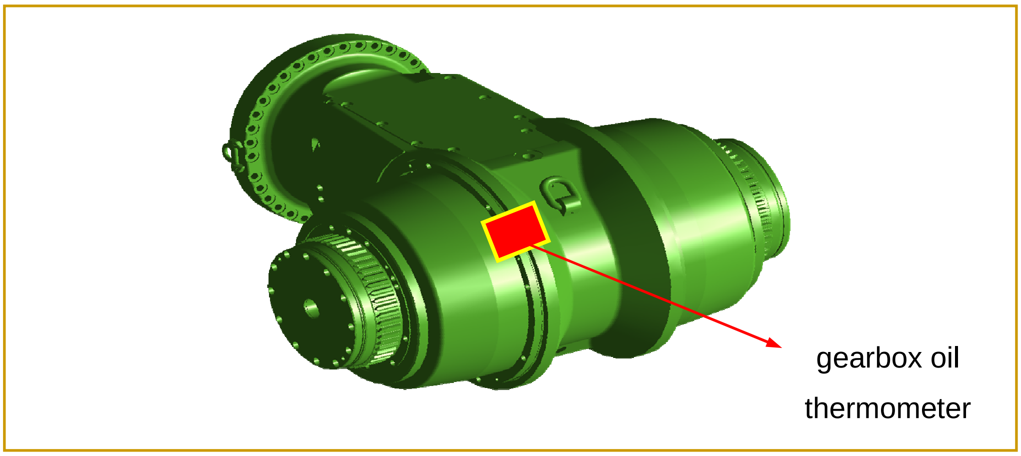


Figure 5-31: Cutter head gearbox, 3D - Illustration.

5.4.3.3.1 Temperature Transducer

To measure the condition of the cutter head gearbox, a combination of temperature and pressure measurements is required. The temperature sensor (Figure 5-32) is used for measuring the temperature of the hydraulic oil inside the cutter head gearbox. The measuring range of this sensor is 0 to 100 ℃.

(Pre-warning is about 90 ℃ degrees and trip at abo ut 95 ℃) with an output signal of 4 … 20 mA.

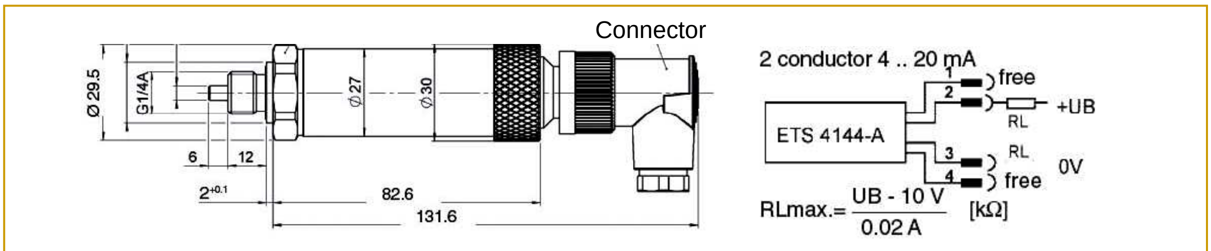


Figure 5-32: Temperature transducer.

5.4.3.3.2 Fluid Flow Indicator

This sensor (Figure 5-33) is able to control water flow as well as oil flow and is mounted in the cutter head gearbox. The measuring range of this sensor is 0 to 50 l/min.
The sensor delivers a 12 V DC signal to the PLC when the fluid flow is less than a certain value.

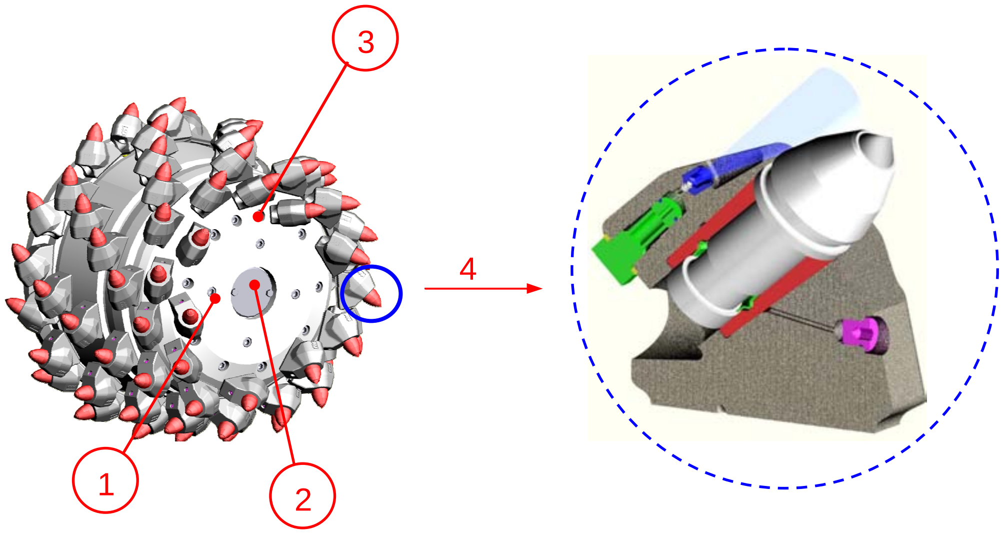
Figure 5-33: Fluid flow indicator.

5.4.3.3.3 Cutter head gearbox Cooling System Pressure Sensor

To measure the condition of the cutter head gearbox, a combination of temperature and pressure is required. A pressure transducer is mounted in the cutter head gearbox cooling system circuit and signals the oil pressure of this system in the range from 0…16 bar. Pressure of oil has to be higher than 1.5 bar.

5.4.3.3.4 Water Pressure Switch

This switch is used to determine the present pressure of the incoming water supply. If the water pressure is higher than a certain value, the contact inside is closed. The operating range of this switch is adjustable, it has a pressure range of 6 to 600 bar and an analogue out put signal of 4 ... 20 mA.
Figure 5-34 illustrates the water spray system, which is used for cooling the picks and dust suppression system. In other words it is used for diluting the methane gas at the site.



1	Cutter head – base element	3	Cylinder bolt with lock washer
2	Water control unit	4	Pick holder with tool system and pick

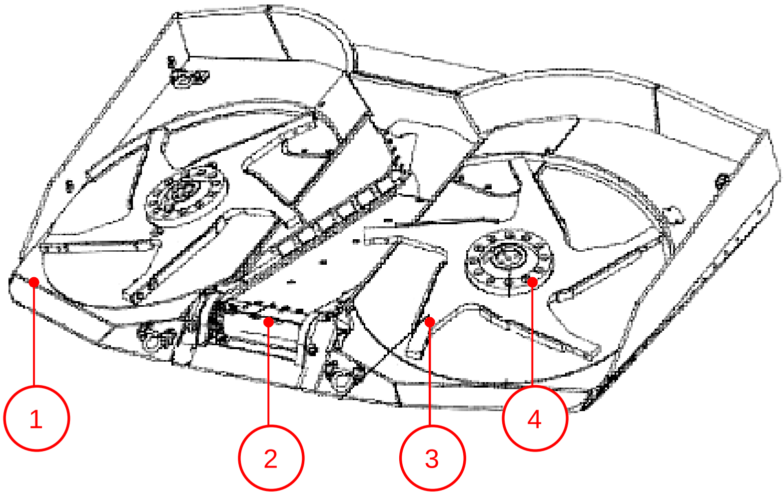
Figure 5-34: Water spray for cooling the picks and dust suppression purposes.

5.4.4 LOADING TABLE

Left / right loader overload / over temperature / blocked

It is important to control the working situation of the blades on loading tables, as shown in Figure 5-35, to avoid blocking the blades or the motors from big rocks. For that reason there are three different inspection methods which do this job simultaneously. Most of the machines, of course, have only an overload inspection system. A bi-metal relay (electronic relay in modern machines) has the responsibility to check if the blade (motor) is overloaded, since there is more heat when the blade is blocked than in motion. With the help of a PTC resistor the over temperature phase of the blade motors is identified by measuring the current flow.

Several blockages in a short time shortens the life of the machine, so if the motor has a number of blockages in a certain time, the motor will be stopped for a longer time (some minutes) to cool down completely.



1	Loading table (maximum loading capacity: 400 m³ / hour)
2	Conveyor front part
3	Spinner (hydraulic motor drive via a bevel-planetary gearbox)
4	Gearbox with E-motor 2 x 36 kW motors (water cooled)

Figure 5-35: Loading table.

5.4.5 MACHINE PITCH & ROLL ENCODERS

5.4.5.1 Tilt-Angle Transmitter (Inclinometer)

Three inclinometers are mounted on the machine - one underneath the apron and two on the machine frame. The inclinometers provide information about the position of the machine. The inclinometers (apron / boom) are used for electronic collision protection between cutter boom and apron. The measuring range is +/- 30° with an output signal of 4 … 20 mA.

5.4.5.1.1 Vertical resolver (Sensor for vertical position of boom)

Has mentioned above! (Boom position sensor)

5.4.5.1.2 Inclinometer Apron (Sensor for position of apron)

The inclinometer housing is filled with oil, which is used for damping purposes and must never be opened.

Figure 5-36: Inclinometer apron.

5.4.5.1.3 Inclinometer Machine (Sensor for position of machine)

This inclinometer, as shown in Figure 5-37 is mounted on the chassis and tells the actual position of the machine.

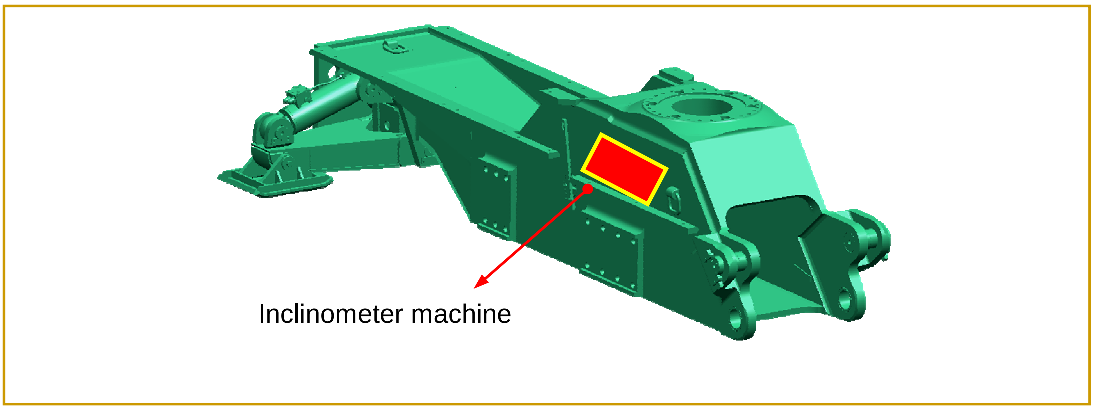


Figure 5-37: Inclinometer Machine.

5.4.6 HYDRAULIC SYSTEM

5.4.6.1 Oil Level Switch

An oil-level switch is used for measuring the hydraulic oil level inside the hydraulic tank and is fitted at the upper end of the tank. Furthermore a transducer has a temperature switch that measures the hydraulic oil temperature inside the tank.

- Immersion depth of the oil-level switch 460 mm
- The contact point for minimum oil level is at 270 mm
- The pre-warning switch point is set at 180 mm

5.4.6.2 Oil Pressure Sensor

The oil pressure sensor (Figure 5-38) is used to measure the pressure of the hydraulic system:

- measuring range 0 to 600 bar
- out put signal 4 to 20 mA
- supply voltage +10 to +30 Volts DC

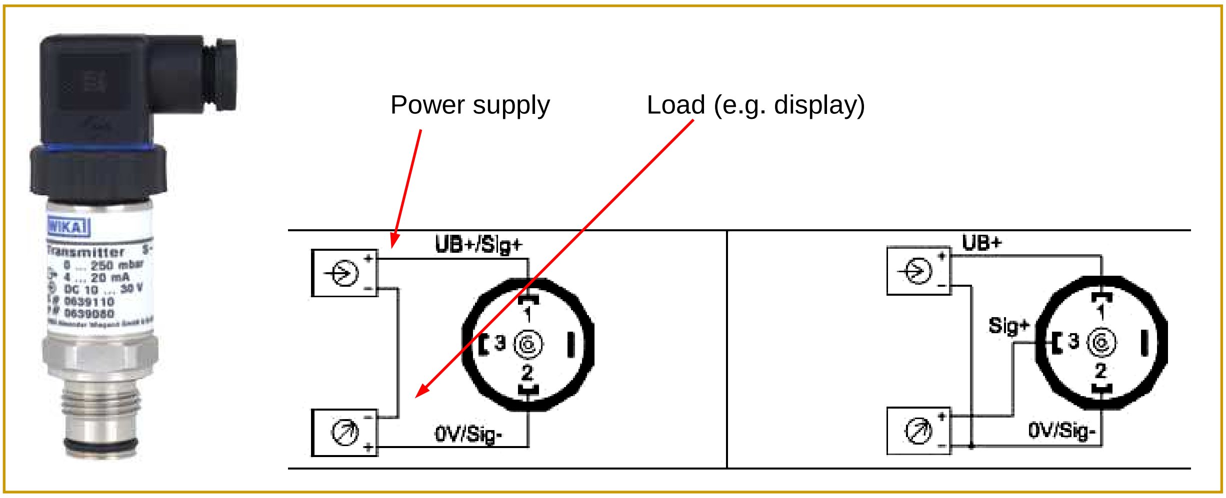


Figure 5-38: Pressure sensor, wiring with 2 and 3 connections.

5.4.6.3 Oil Temperature Sensor

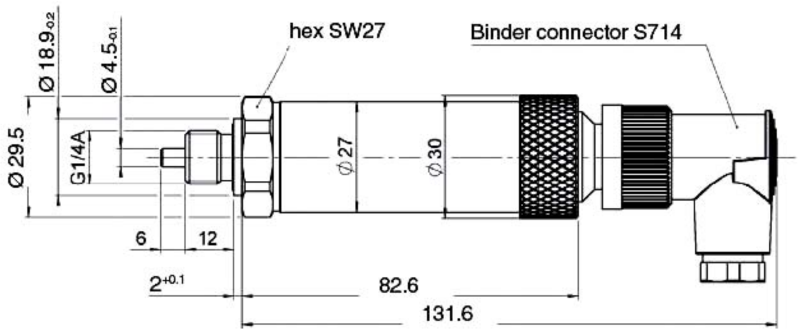
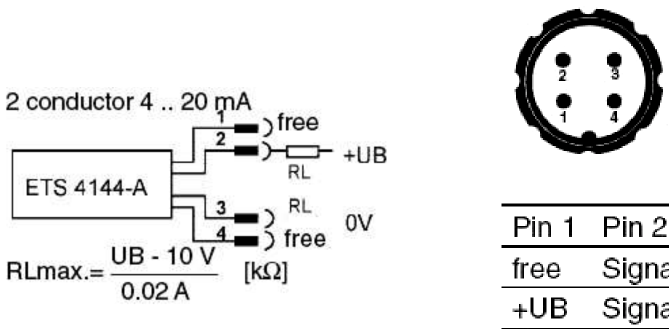


Figure 5-39: Electronic temperature transmitter.

Accuracy: 1.0

Minimum range of temperature: 100. 0

Maximum range of temperature: -25.0



Pin 1	Pin 2	Pin 3	Pin 4
free	Signal	Signal	free
+UB	Signal	0V	⏚

Figure 5-40: Electronic temperature transmitter, connection circuit.

5.4.6.4 Clogging Indicator

The clogging indicator Figure 5-41 is mounted on the hydraulic filter and signals the contamination of the hydraulic filter. It sends a 12 V DC signal (converts hydraulic or pneumatic signals to electrical signals) to the PLC in case of different pressure over range between the input- and output sides of the filter. The stepless knob is for setting the switching

points. In the ATM clogging indication system two different indicators are used, one for the supply line and the other for the return line (24 V).
Working range: 0.5 to 8 bar

5.4.6.4.1 Art of Indication

1) Electrical Switch
“Deltadyne electrical switches have an automatic reset function that allows them to be used as system warm-up monitors. High fluid viscosity associated with low temperature start-ups will cause a higher pressure drop across the filter element. Deltadyne switches will signal high differential pressure until the system reaches operating temperature. As the system warms up, the differential pressure is reduced, and the range spring returns the piston assembly to its normal position, thus restoring the magnetic force between the magnet and the actuator lever.

The restored magnetic force is sufficient to overcome the switch spring force, allowing the single pole double throw switch (SPDT) to signal a differential pressure below the switch setting.

2) Visual Indicator
Memory: All Deltadyne visual indicators show whether a preset differential pressure has been exceeded at any time – even after the system is shut down. When the factory-set differential pressure is exceeded, the red button pops up and stay up until it is manually reset. When the differential pressure is reduced, the range spring returns the piston assembly to its normal position; however, the gap between the magnet and the now extended indicator button is too great for magnetic force to overcome the button spring force. The button, therefore, remains in the extended position until differential pressure is reduced and the button is manually reset”. [18]

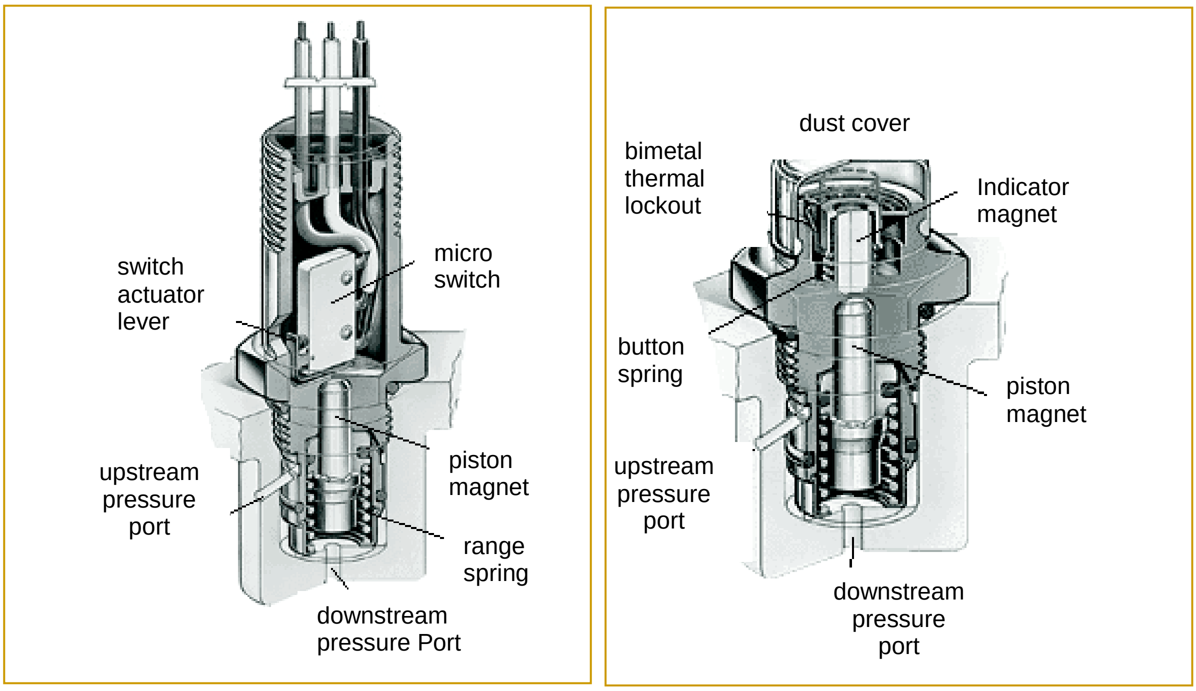


Figure 5-41: Clogging indicators in pressure line (L: Electrical R: Visual).

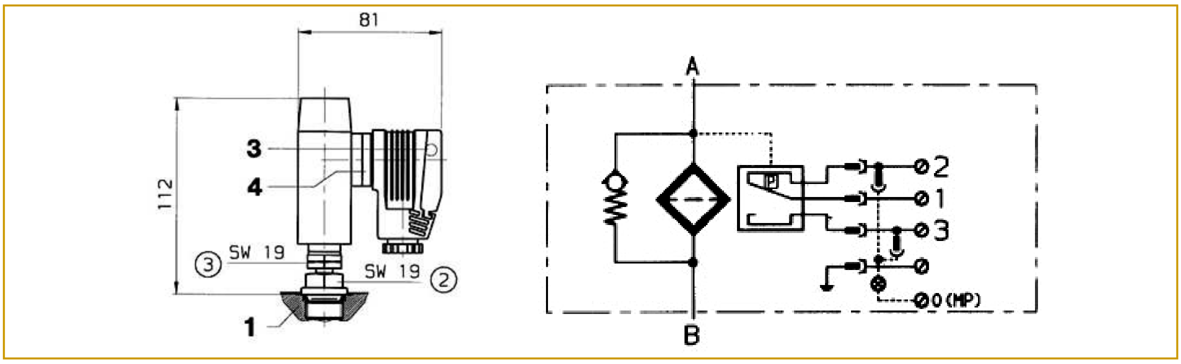


Figure 5-42: Clogging indicator in return line (visual).

5.4.7 Safety foot switch (Dead man switch)

The safety foot switch (dead man switch), which is shown in Figure 5-43, is mounted on the bottom of the driver's cabin. It is used to lock / unlock the start process for the hydraulic engine.

Before the hydraulic engine is started by the buttons “UNLOCK” and “HYDRAULIC START”, the dead man switch needs to be pressed and released at once.

If not, the start procedure is locked and the following messages appear on the monitor.

- Hydraulic pump is locked
- Pump stop press/release dead man

Figure 5-43: Safety foot switch.

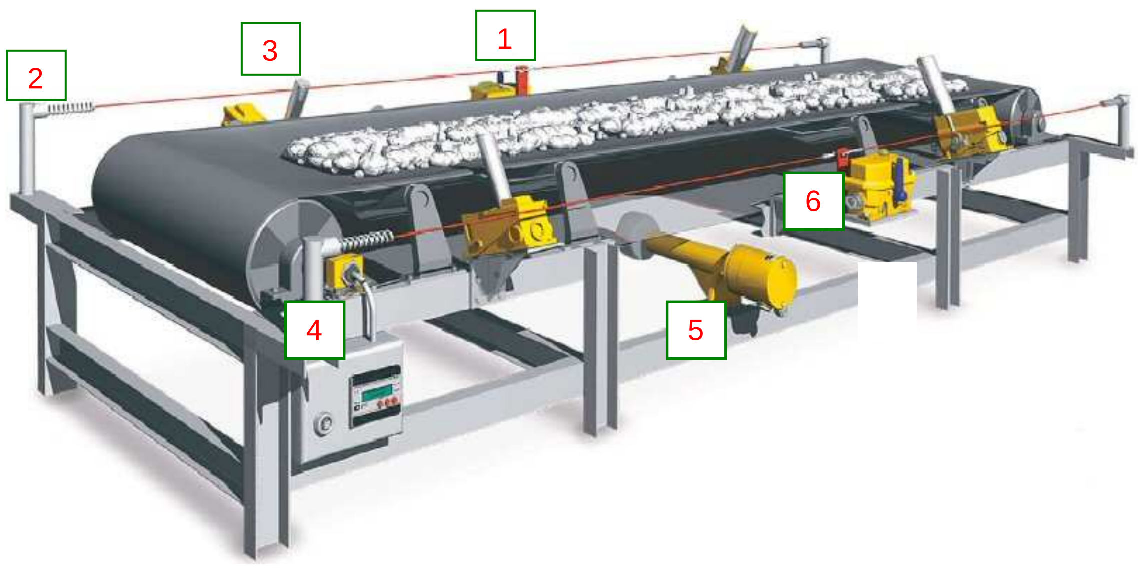
Furthermore, all hydraulic functions can only be driven with the dead man switch pressed, (cutter, booster pump).The electric motors can still function.

To start the loading system and keep it in operation, the dead man needs to be pressed as well.

6. SENSORS FOR BELT- / BOOM CONVEYORS

6.1. GENERAL

In recent years, conveyor belts have been used in completely new areas, particularly where the location of roadways is extremely difficult, where these have to go uphill and down dale and have to overcome curves, while at the same time transporting bulk solids in a steady flow. A belt conveyor consists of two pulleys, with a continuous loop of material - the conveyor belt - that rotates about them. One or both of the pulleys are powered, moving the belt, and the material on the belt, forward. The powered pulley is called the drive pulley while the unpowered pulley is called the idler. There are two main industrial classes of belt conveyors; those in general material handling such as those moving boxes along inside a factory and bulk material handling such as those used to transport industrial and agricultural materials, such as grain, coal, ores, etc., generally in outdoor locations. Monitoring the speed of the belt is, for example, necessary in combination with other factors for calculating the handled material; its control is also important so that the belt remains undamaged during operation, and to ensure that all bearings are lubricated. There are many more examples which illustrate the necessity of sensors on conveyor belts as shown in Figure 6-1. In the following chapter the use of sensors in conveying technology will be examined.



1	Pull wire switch	4	Under speed sensor
2	Compensation spring	5	Slip monitor
3	Off-track switch	6	Belt weigher

Figure 6-1: Sensors on a belt conveyor.

6.2. BELT-HEALTHY SENSORS

6.2.1. Misalignment (off-track) Switch

Off-track switches are used along belt conveyors to reduce the danger of damage or destruction of the belt by misalignment (Figure 6-2, B). The misalignment switches should be installed in pairs, on both sides of the conveyor. If the conveyor belt should then misalign from the correct track, one of the switch roller levers will be touched by the edge of the belt and be displaced. The resetting force of an internal spring prevents its accidental operation. The maximum displacement angle of the roller lever is about 15°. A two-stage switch is also available, first stage for signalling/warning, when the lever is displaced by approx. 10°, and the second stage for cut-off, when the lever is displaced by approx. 18° (Figure 6-2, C).
The standard switch automatically resets in the event that the belt realigns itself.

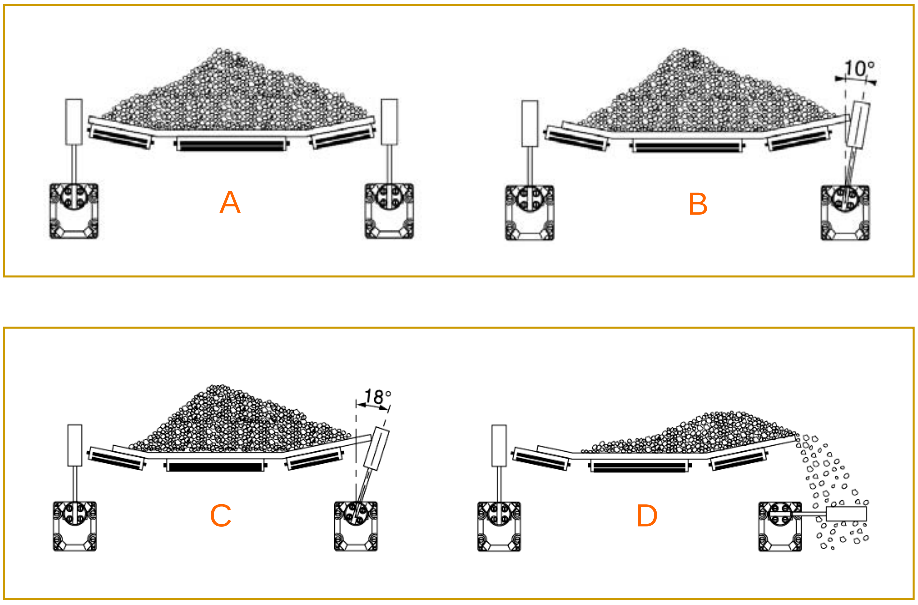


Figure 6-2: Misalignment switch for conveyor belt.

The following photo (Figure 6-3) shows the installation of this switch on conveyor belt.

Figure 6-3: Misalignment (off-track) switch on site.

6.2.2. Damaged Belt Detector

6.2.2.1. Electromechanical System

Principle of Operation:

An electromechanical damaged-belt detector, as shown in Figure 6-4, operates using a spring-loaded ball and socket connected to two plunger-type micro switches. As an object hanging below the belt sweeps away the cable, it pulls the ball connector from its socket. When this happens a spring-loaded shaft is released and the switch is deactivated, causing them to sound an alarm, turn on a warning light or shut down the system. All that is required to reactivate the detectors is to snap the ball connector and cable back into its socket.

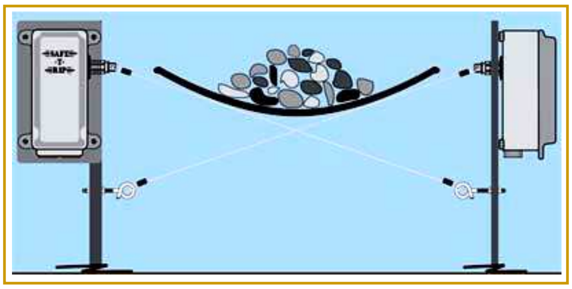


Figure 6-4: Damaged belt detector (Electromechanical).

6.2.2.2. Electromagnetic System

A damaged conveyor belt, which may resulted from the belt being slit longitudinally, foreign bodies, wrongly installed scrapers, etc, can cause long and expensive servicing when it is not early enough detected. The system is preferred in critical areas like loading points with high impact energies. This system consists of electro inductive conductor loops which are vulcanized into the carrying or running side of the belt (Figure 6-5). Monitoring sensors are fitted in front of a critical area and behind it to scanning the integrated conductor loops. The surface comparison between the belts previous and its present revolution is possible, so that the damage can be detected. The conveyor belt is immediately halted when it is slit by a foreign body, and the electrical circuit is interrupted as a result in order to prevent greater damage. The belt damage can thus be reduced. In addition, all of the conveyor belt's surface defects are stored in a data bank and are available for further analysis.

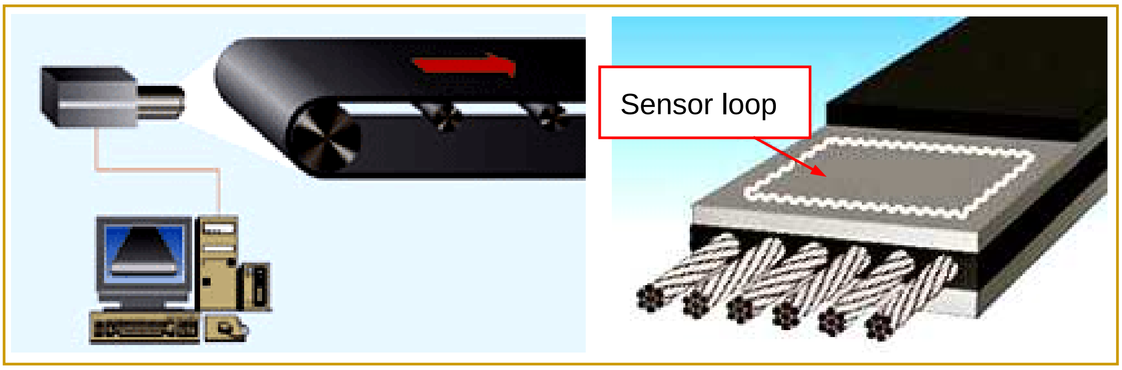


Figure 6-5: Damaged belt detector (Electromagnetic).

6.3. BELT SCALES

6.3.1. Principle of Operation

A typical belt scale system is composed of a weigh bridge structure supported on load cells, an electronic integrator, and a belt speed sensor, as shown in Figure 6-6. The rate of the material conveyed is computed using the equation weight x speed = rate. The integrator receives input in the form of electronic pulses per revolution from a belt speed sensor connected to a tail or bend pulley, and a voltage signal from load cells which measure the material weight on the belt. Using these two points of data, the integrator calculates the rate of material transferred along the belt in pounds or tons per hour.

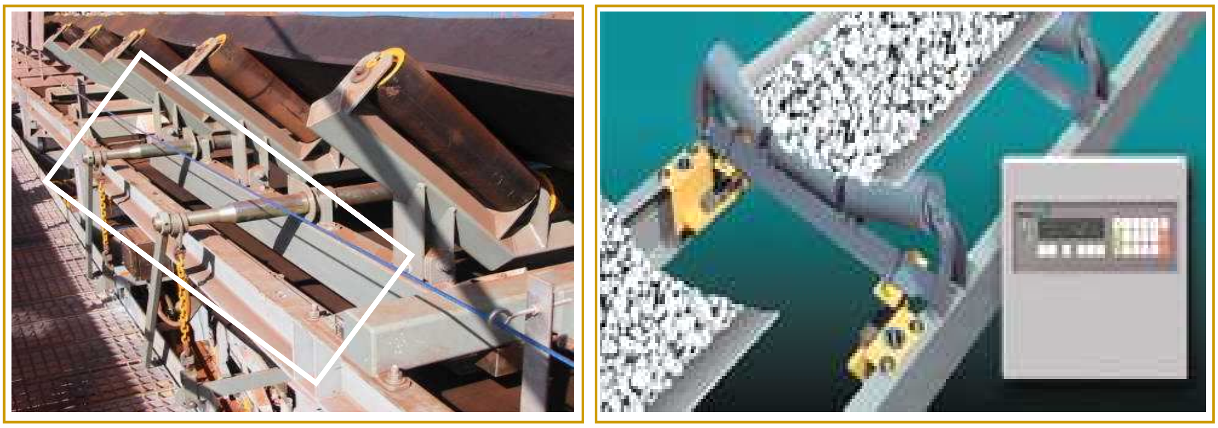


Figure 6-6: Belt scale.

6.3.2. Belt scale location

The scale should be located at a sufficient distance from the feeding, so the material has time to become properly profiled and settled on the belt. This distance will vary depending on the conveyor design, flow rate, and material; however, about 8 to 10 m is usually acceptable. Installing a scale in an area of high tension along the belt (near the head pulley) can significantly decrease the accuracy. It is possible to configure a scale to operate in an area of high tension; however, special care must be given to the installation, particularly the alignment. Since many conveyors may curve up or down along some point, it is important to locate the scale an appropriate distance away from the tangent points of the curve.
Material to be weighed, belt capacity (tons/hour), belt speed (feet/minute), idler/trough angle and diameter, belt width (inches), carrying idler spacing, and conveyor incline angle play an important role in selecting an optimal belt scale.

6.4. BULK FLOW MEASUREMENT

6.4.1. Laser Measurement System

These sensors work according to the principle of time-of-flight measurement. A pulsed laser beam is emitted and if it encounters the bulk goods it is reflected and it is registered in the scanners receiver. The time the beam travels between transmission and reception of the impulse is directly proportional to the distance between the scanner and the bulk material. The fan-shaped scan of the laser is fulfilled by an internal rotating mirror. The volume or throughput at any time can be determined by combining the input data with other known quantities such as belt speed or the density of the transporting material. Figure 6-7 shows the configuration of LMS (laser measurement system) with the data interface.

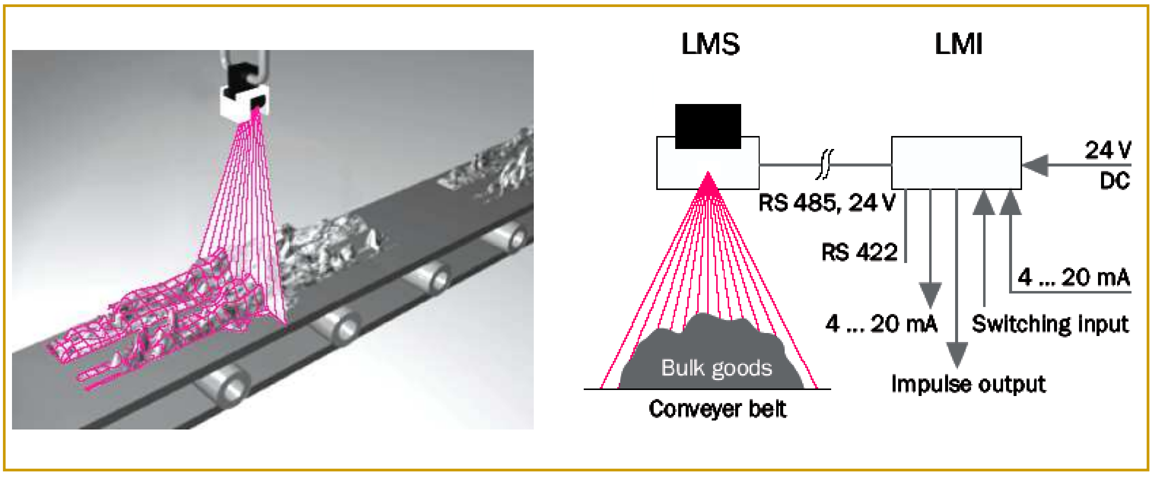


Figure 6-7: Bulk flow measurement (radiation measuring principle).

6.4.2. Impact Plate Measuring Principle

This principle is based on the reactive force generated when a dry material, directed by an inlet pipe (Figure 6-8), strikes a steel impact plate mounted at a defined angle.

The horizontal component of the reactive force will be sensed via a load cell and processed electronically into flow rate and total weight values.

Figure 6-8: Impact plate measuring principle.

6.4.3. The “CORIOLIS” Measuring Principle

The coriolis principle uses the science of particle acceleration and its resultant forces to measure flow rate and total weight at accuracies of +/-0.5%. It consists of partitioned measuring wheel, mounted on a drive shaft inside a central dust tight housing (Figure 6-9). An electric motor mounted outside the housing drives the shaft. Material enters the unit through an off centre inlet and discharges through a centre outlet below the measuring wheel which rotates at a constant speed. Material entering the unit flows into the top of the measuring wheel and is deflected outward in a radial direction creating a coriolis force. The device sees this force as a change in torque which is detected by a strain gauge load cell.
The output of the load cell is electronically processed to produce flow rate and total weight values. The advantage is that, this kind of flow meter is not affected by material density, friction or in-feed drop height.

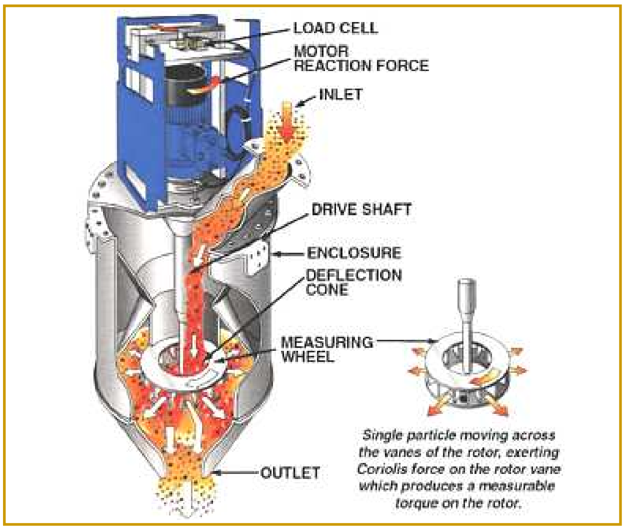


Figure 6-9: Coriolis measuring principle.

6.4.4. “DEFLECTION CHUTE” Measuring Principle

This system, as shown in (Figure 6-10), is also based on reactive force, but in place of an impact plate, a curved measuring chute is used. As a result, impact is replaced by radial acceleration and chute deflection that a load cell detects. This signal is then electronically processed to produce flow rate and total weight values.

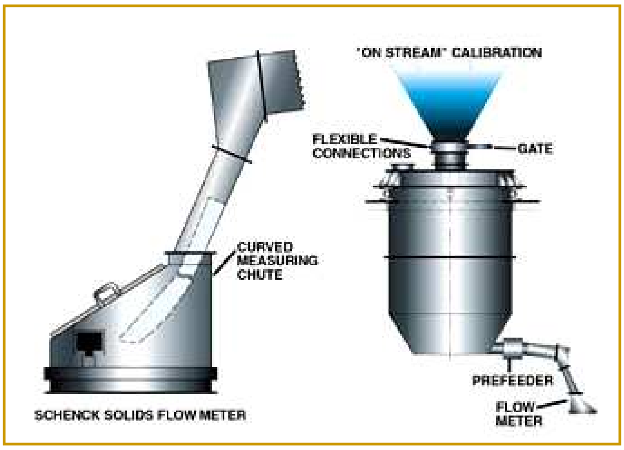


Figure 6-10: Deflecting chute measuring principle.

6.5. BOOM CONVEYOR (BC)

6.5.1. BC Brake Lifted Switch

The boom conveyor lifted switch is in deed a micro switch which senses that the conveyor brake has lifted fully and enables the conveyor to start. If the switch fails to operate within five 5 seconds of brake motor stating, in any mode of control, an alarm is raised and conveyor drive is stopped.

6.5.2. BC Under-Speed Sensor

This proximity switch (Figure 6-11) provides pulses from the sensing flags on the non-driven pulley. This built-in speed sensor switch provides an up to speed signal to the control system and is adjustable by a built-in potentiometer.

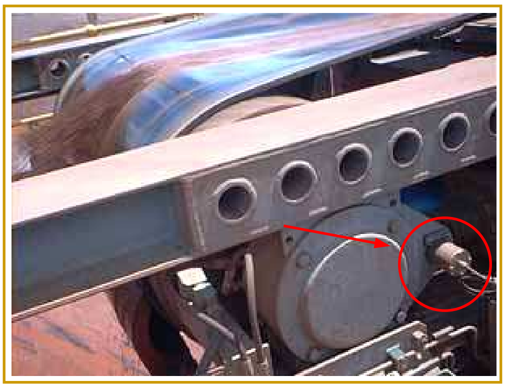


Figure 6-11: Under-speed sensor.

6.5.3. Coupling Over-temperature Switch

This switch, when operated, indicates that the drive fluid coupling over-temperature "plug", has operated. This will stop the conveyor, and raise an alarm.

6.5.4. Boom Ultrasonic

The boom conveyor receives the bulk material from the yard conveyor/tripper and transfers it to the stockpile. After a time the stockpile height increases and to prevent a collision between the stockpile and the conveyor boom, an ultrasonic sensor, as shown in Figure 6-12, is mounted on the boom which constantly senses the distance. When the distance is too small, an alarm is raised and then the machine stops. This sensor operates in the 5-30 kHz range. That means superior performance in dusty, windy or steamy atmospheres.

Figure 6-12: Boom ultrasonic sensor.

6.5.5. Pull Rope Switch

Pull wire (Figure 6-13) makes it possible to cut off the work at any time or mode when the workers are in a dangerous situation. The system consists of a switch box (when necessary, more than one switch in defined intervals) and a wire along the conveyor boom which is connected to the switch. With pulling the wire, the switch cut off, and the system stops. The tripping occurs when one or both trip wires are removed, over tensioned, or activated, and the manual trip is possible via a reset knob. This system works with the voltage of 26.5 to 31.6 Volts DC.

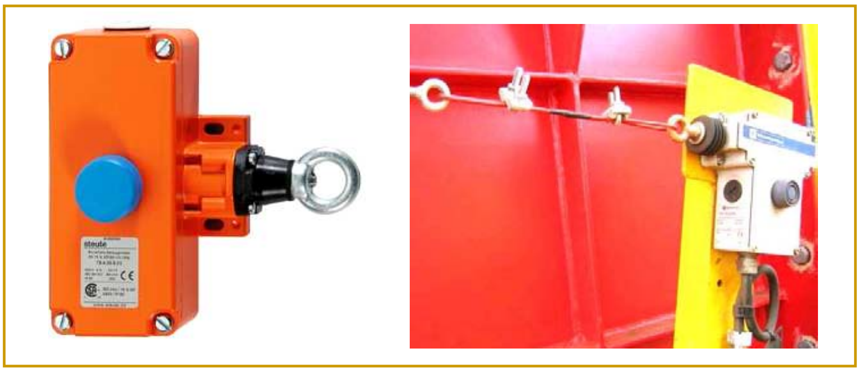


Figure 6-13: Pull wire system.

7. SENSORS FOR BULK MATERIALS HANDLING MACHINERY

7.1 Stacker and Reclaimer

A stacker (Figure 7-1) is a large machine used in bulk materials handling applications. A stacker's function is to stack bulk materials such as ores and cereals onto a stockpile.

A reclaimer (Figure 7-2) is used to recover the material. Stackers and reclaimers are rated in tph (tonnes per hour) for capacity, and normally travel on a rail between stockpiles in the stockyard. The range of stackers and reclaimers (e.g. built by VAMH) starts from minimum tonnages of 150 t/h to more than 10,000 t/h. The boom length of a machine can range between 10 and 60 meters.

Stackers and reclaimers were originally manually controlled but modern machines are typically semi-automatic or fully automated.

The controlling system used is typically a PLC (Programmable Logic Controller) with an HMI (Human-Machine Interface) for display, connected to a central control system.

Figure 7-1: Stacker.

Figure 7-2: Stacker / Reclaimer.

Nowadays different kinds of sensors are used on surface mining machinery for the purpose of increasing the accuracy, safety, operating efficiency and decreasing the troubles during operation and eventually lowering the costs. The operator can read the data and signals on the panel, as shown in Figure 7-3, which have been sensed with the help of different sensors on the machine. This chapter gives a detailed view in the field of sensorics of stackers and reclaimers.

Figure 7-3: Stacker/reclaimer control panel.

7.1.1 Transactional Motions

A stacker can usually move in at least two directions: horizontally along the rail and vertically by luffing its boom and some stackers are able to rotate by slewing the boom. This allows a single stacker to form two stockpiles, one on either side of the conveyor. Minimizing dust, when material is handled, will be achieved by reducing the height that the material needs to fall to the top of the stockpile by luffing the boom. The boom is luffed upwards as the stockpile height grows.
A bucket wheel reclaimer can typically move in three directions: horizontally along the rail, vertically by luffing its boom and rotationally by slewing its boom.

7.1.2 Travel Limits

The position of the machine can be determined via different software and switches. It is used to control the travelling of the machine on tracks. The operators and/or engineers can for example determine the end limits of travel and maintenance position of the machine.

7.1.2.1 Software Limit

This is a PLC software limit which is approximately 10 metres prior to the maintenance / storm tie down long travel position at one end. If operated, the long travel will decelerate to a stop and holding brakes will be applied.

7.1.2.2 Maintenance / Storm Tie Position

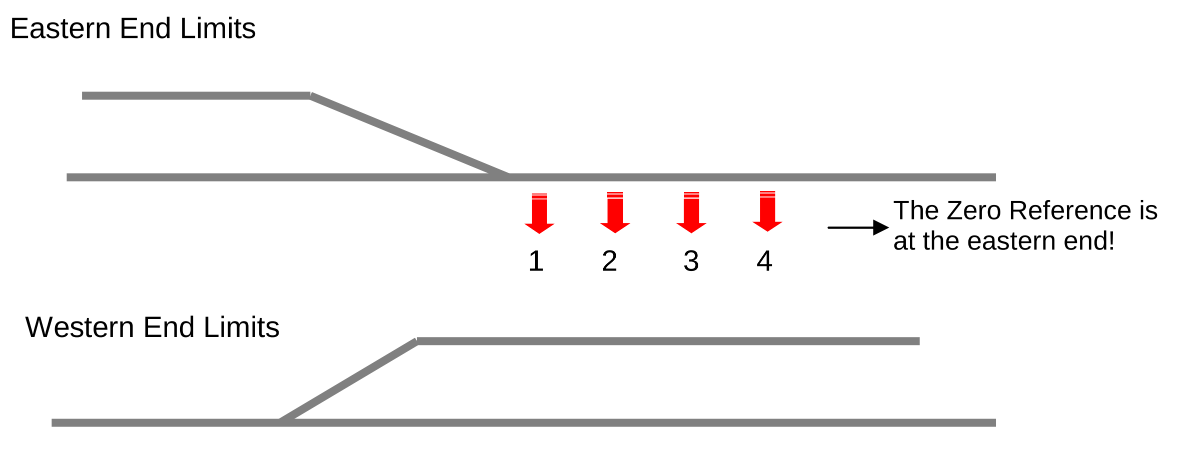
This is at one end only (north, south, east or west). The machine can travel to this position, past the normal software operational limit only if the machine is in “local” mode.

7.1.2.3 Operational End Limit Proximity Switch

This switch is positioned approx. 5 metres beyond the tie-down position, at one end and beyond the normal decelerating and stopping position of the software limit at the other end. This proximity switch position will cause an emergency stop of the long travel to occur, and an alarm to be raised.

7.1.2.4 Emergency End Limit

This limit switch is mounted at the end limit of travel at either end of the track (Figure 7-4; Figure 7-5). If operated, it will cause the cutting off of all power (drives and brakes) to the long travel drive system and an alarm is also raised.



1	Operational limit software limit eastern end limits
2	Maintenance / storm tie down position
3	Operational end limit
4	Emergency end limit switch

Figure 7-4: Emergency end limits.

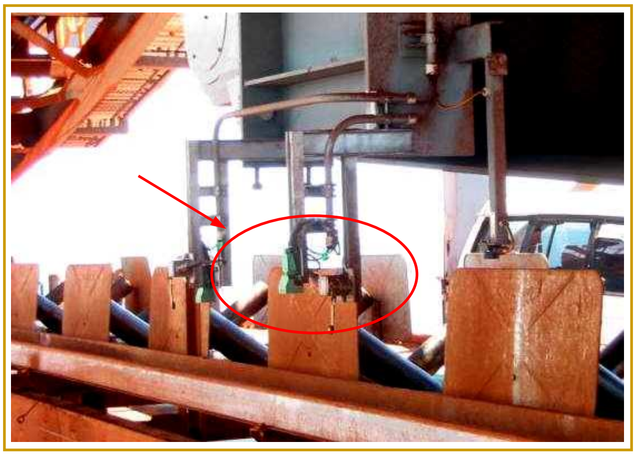


Figure 7-5: Emergency end limit sensor.

7.2 LONG TRAVEL DRIVE (LTD)

The machine is designed to travel longitudinally along the yard. A maintenance / storm tie down position is located at the end of the track.

- Relocation speed ca. 30 m/min
- Local / operation speed ca. 6 m/min

The speed, acceleration, and deceleration of the long travel drive system are controlled via a single VVVF drive controller located in the E-House and the LTD encoder, as shown in Figure 7-6, gives the present position of the machine.

Figure 7-6: LTD-encoder.

7.2.1 LTD Brake Lifted Switch

There are about 6 to 14 switches on the machine which indicate that the disc brake has lifted, and is used to confirm correct operation prior to any long travel motion. An alarm is to be raised if not detected within 2 seconds.

7.2.2 Boom in Cradle (storm tie down) Position Proximity Switch

The position proximity switch (Figure 7-7) is mounted at the bucket wheel end of the boom and is operated by a spring mounted striker which is activated by the boom lowering into the maintenance cradle (located at one end of the track). When this switch is activated, it stops and inhibits all slews and long travel motions such as any luff-down motion and raises an alarm.

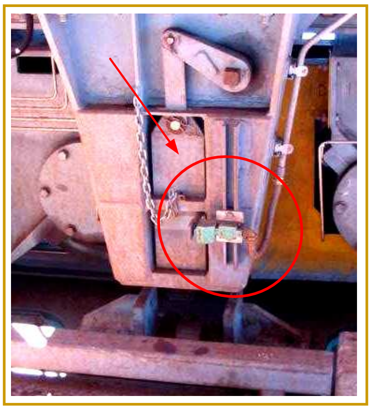


Figure 7-7: Boom in cradle position proximity switch.

7.2.3 LTD Emergency End Limit Relay

This limit switch, when operated, indicates that the machine has traveled past all other software / tag post end limits and reached the emergency end limit of east or west travel.

7.2.4 LTD Operational End Limit Proximity Switch

This switch (Figure 7-8) indicates the machine has traveled past the normal software / tag1 post operational limits of travel (including eastern / western tie down position) when operated, and this will cause an emergency of the LTD via PLC controls de-energizing the LTD main contactor.

1) Positional update tags: At an interval of every some meters over the entire travel distance of the machine, a "binary coded" striker post is mounted on the yard conveyor structure. The striker posts are sensed by a row of 6 proximity switches mounted on the machine.

Figure 7-8: LTD limit switch.

7.2.5 Telsor Tag Reader System

This system works with 24 DC Voltage and consists of a "tag reader" head mounted on the portal section of the reclaimer, and coded tags mounted along the yard conveyor structure at intervals of about 30 meters. The "tag reader" reads the tags and provides the PLC (via inputs) tag values (i.e. 1 to 20, which depends on mounting position representing a set travel position).

The PLC will re-synchronize the encoder count value with the reading of each tag to increase the accuracy, and will raise three alarms from the tag system when the encoder has travelled approximately 30 meters or more, and no tag seen or tag value read is not the next expected value or when a tag reader head error appears.

If the reclaimer has travelled approximately 60 meters without seeing a tag, or alarm two or three is activated, the PLC will latch the fault, stop long travel motion in all modes except LOCAL.

7.2.6 Anemometer (Wind Speed Sensor)

The anemometer is mounted on the top of the boom conveyor structure near the tail of the boom and measures the wind speed which, via a PLC analogue input, enables the PLC to monitor and set off alarms at wind speeds of 16+ meters per second, and shut down reclaimer operations at wind speeds of 20+ meters per second. The alarm "high wind", (16+ m/s), will be indicated on the HMI. If wind speeds greater than 20 m/s are detected for two minutes, this will cause the bucket wheel to shut down, and after a timed period to allow the boom conveyor to empty, the boom conveyor will stop, and automatic reclaim operations will also be stopped. If the "high/high winds" set point of 25 m/s is registered for one minute or longer, the "storm lock" alarm is raised, and the bucket wheel will stop immediately, and boom conveyor will shut down after the elapse of the "run down" timer.

7.3 CABLE- / HOSE REELER

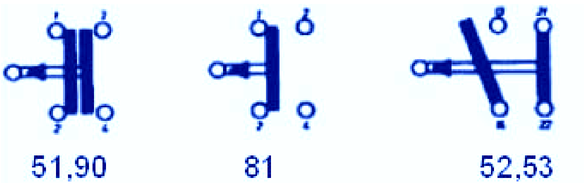
7.3.1 Geared limit switch

7.3.1.1 Reel- Empty / Full Switch

This hunting tooth type switch (a micro switch with snap or push action), as shown in Figure 7-9, mounted in the slip ring housing and indicates whether all cable has been expelled from the reeler or the reeler is full. It is set to operate a position prior to the long travel emergency end limits. If “EMPTY” state activated, it will stop the reeler, and long travel drive in emergency stop mode, and an alarm is to be raised.

Figure 7-9: Geared limit switch.

Different contact types are shown in Figure 7-10.



51, 90 … snap action
81 … push action
52, 53 … snap action, push

Figure 7-10: Switch contact types.

Contact Adjustment:

Two infinitely adjustable cam discs are provided for each contact. The cam discs can be set independently from each other after loosing the nut (Figure 7-11). The safety plate prevents a previously adjusted cam disc from changing because of the adjustment of the subsequent disc. After adjustment of the switching points, the nut must be tightened by a wrench. The cam discs are designed to dispose of a constant useful travel and over travel. In relation to the position of the cams for one contact, the over travel can be doubled and the useful travel can be reduced accordingly. When exceeding the over travel, the switch is not damaged. The contact, however, is opened or closed again.

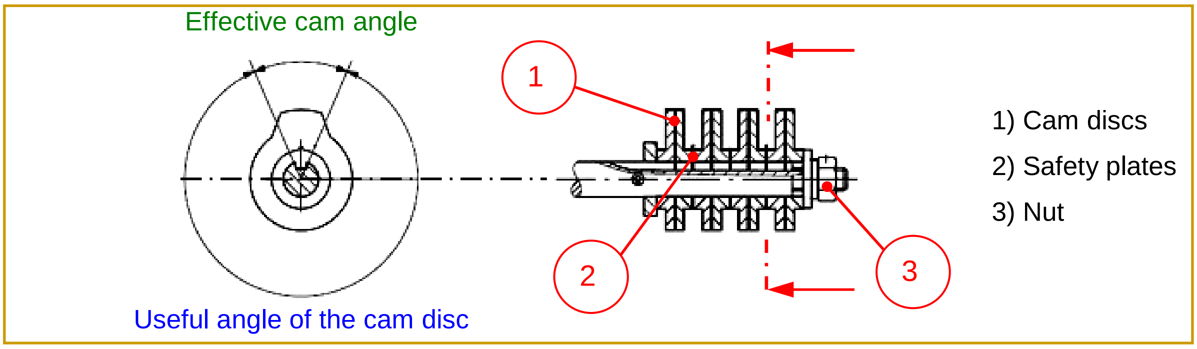


Figure 7-11: Geared limit switch, contact adjustment.

7.3.1.2 Third Last Turn Warning / Last Turn Protection

With the help of the geared limit switch it is also possible to warn when the third last turn signal existing to protect cable or hose damages for extra extension.

7.3.2 Under Tension Switches

Theses are in fact inductive proximity switches, shown in Figure 7-12, which are mounted on the cable pendulum roller guide assembly through which the cable leaves / enters the reeler, these switches detect that the pendulum is vertical, indicating the cable is not being correctly reeled in (i.e. stack/loose). If activated the long travel goes immediately in emergency stop mode and an alarm is to be raised.

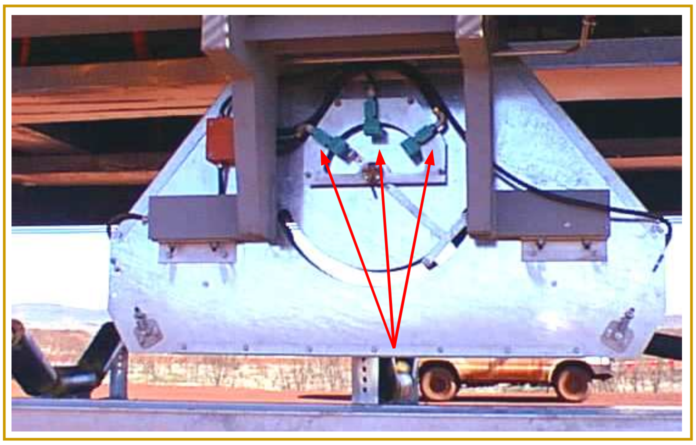
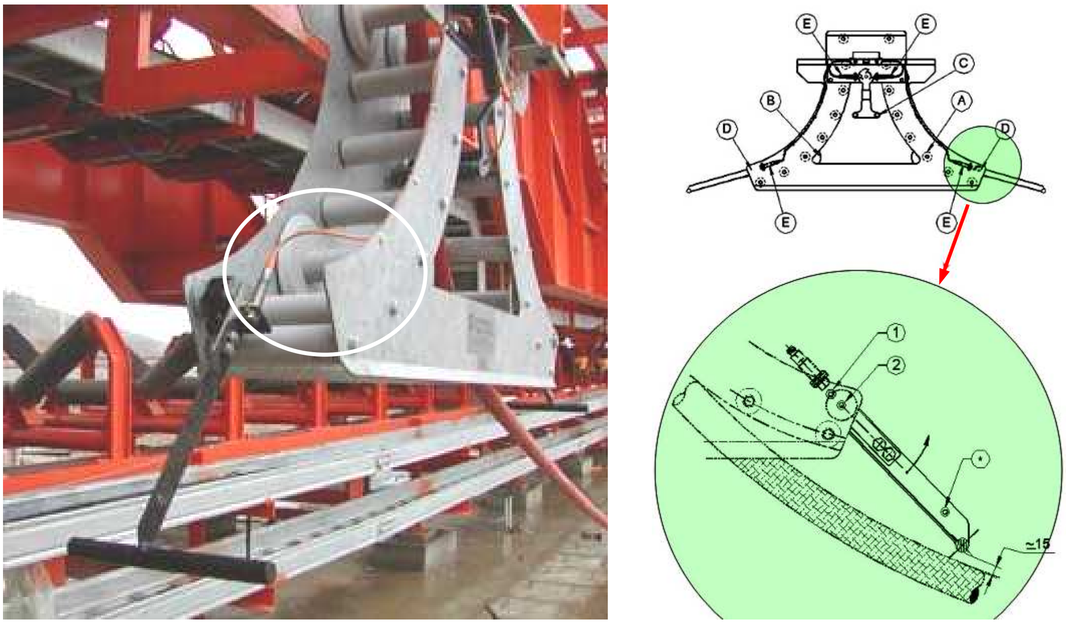


Figure 7-12: Under-tension switch.

7.3.3 Over Tension Switches

Over-tension switches (Figure 7-13) mounted on the cable pendulum roller guide. If either of these switches is activated, it indicates that the cable tension is high and the cable is not “playing out” correctly, the long travel is stopped immediately in emergency stop mode and an alarm is to be raised.



A	Guide roller	D	Elastic hub (over tension switch)
B	Guide roller (with flanges)	E	Proximity switch
C	Roller (under tension switch)	1,2	Positioning screws

Figure 7-13: Over-tension switch.

7.3.3.1 Calculation of wrap angle forces

The rap angle forces on the cable (Figure 7-14) can be calculated with the help of the following equations.

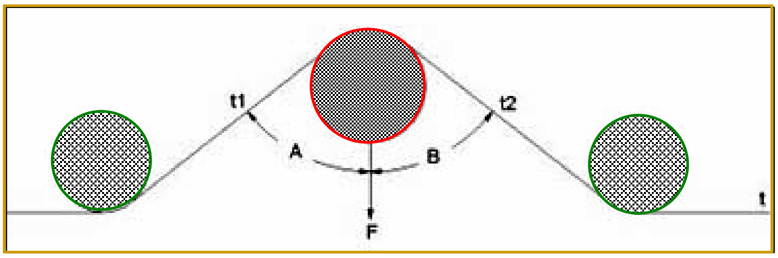


Figure 7-14: Calculation of wrap angle.

The downward force F acting on the central sensor is:

$$F = t_1 \cos A + t_2 \cos B \qquad (7.1)$$

If the angles A and B are the same, the formula becomes:

$$F = 2 \cdot t \cos A \qquad (7.2)$$

The total tension t on the material is therefore:

$$t = \frac{F}{2 \cos A} \qquad (7.3)$$

7.4 CHUTE SYSTEM

7.4.1 Blocked Chute Tilt Switch

The blocked chute tilt switch is mounted in the transfer chute as shown in Figure 7-15, (between the yard conveyor and the boom conveyor) and provides feedback to the control system. It stops the yard conveyor and an alarm is raised if activated for two seconds or more continuously when the chute is clogged. The standard switch which is used for this function is a SPDT switch.

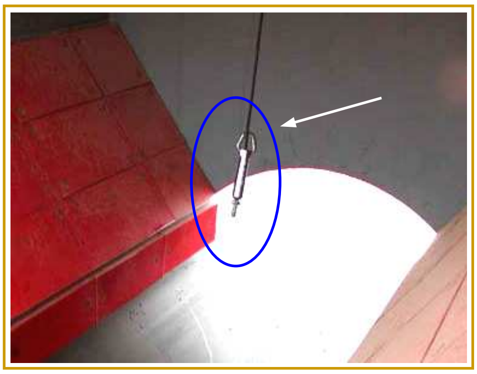


Figure 7-15: Blocked chute tilt switch.

SPDT… Single Pole, Double Throw ON-ON

This switch, as shown in Figure 7-16, can be “ON” in both positions, switching on a separate device in each case. It is often called a changeover switch. For example, a SPDT switch can be used to switch on a red lamp in one position and a green lamp in the other position.

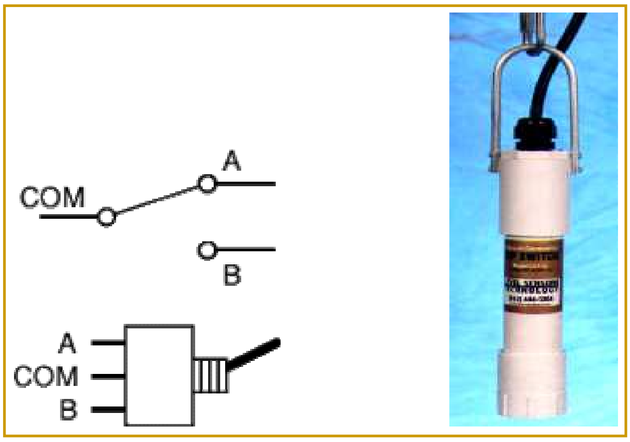


Figure 7-16: SPDT switch (L) blocked chute tilt switch (R).

A SPDT toggle switch may be used as a simple on-off switch by connecting to COM and one of the A or B terminals shown in the diagram. Switches are usually not labelled because “A” and “B” are interchangeable. A special version of the standard SPDT switch which has a third switching position in the centre “OFF” is also available. (ON)-OFF-(ON) versions are also available where the switch returns to the central off position when released.

7.4.2 Chute Access Door Closed Proximity Switch

This proximity switch (Figure 7-17) is activated when the access door to the transfer chute is closed. If the door is open, the conveyor stops and an alarm raised.

Figure 7-17: Chute access door closed proximity switch.

7.4.3 Impact Table Chute Present proximity switch

This proximity switch indicates whether the removable transfer chute to the yard conveyor is in its position or not. This switch must be on for the boom conveyor to run in all modes other than local. If no signal is sensed, it raises an alarm and stops the boom conveyor.

7.5 SLEW DRIVE SYSTEM

7.5.1 General

The slew mechanism is designed to provide up to +/- 110° of slew motion, as shown in (Figure 7-18). The control system is designed to provide four quadrant operations on the northern and southern sides of the machine.

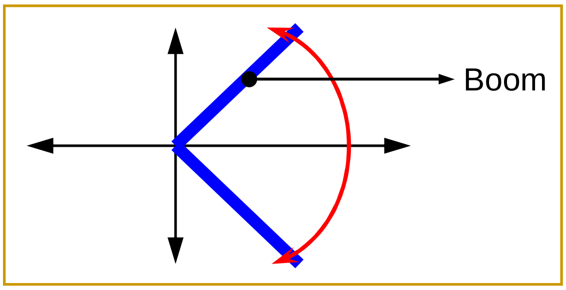


Figure 7-18: Slew motion of the boom (Top View).

7.5.2 Definition of Angles

For clarity, the slew angle display on the HMI will be indicated as 10-350°, where 180° represents the boom parallel with the yard conveyor as shown in Figure 7-19.

Inner slew angle = the edge of the stockpile closest to the yard conveyor / reclaimer.
Outer slew angle = the edge of the stockpile furthest away from the yard conveyor / reclaimer.

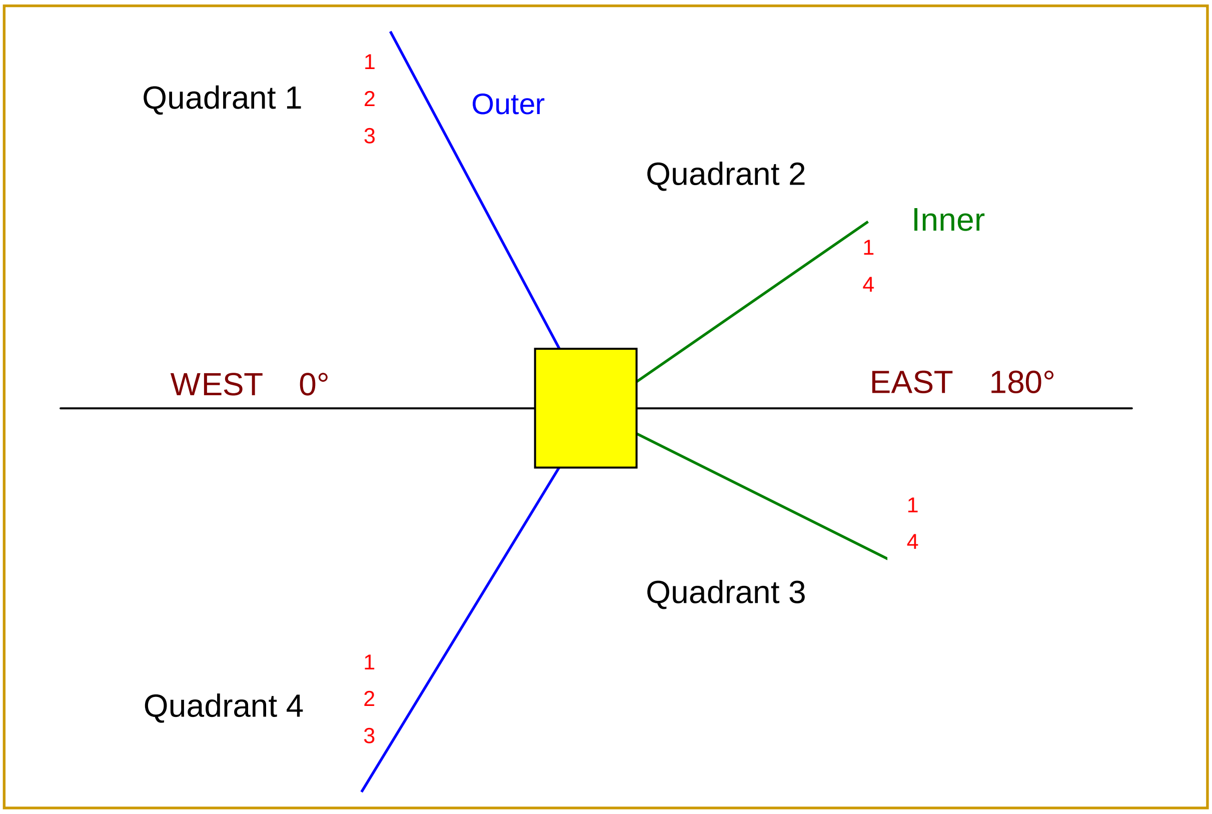


Figure 7-19: Diagram of slew angles and limits.

7.5.3 Stopping Methods of the slew Drive

The sequence of stopping the slew system is as follows:
In the normal stopping mode, the VVVF drive controller will decelerate the slew motion to a standstill and after a short delay (approximately two seconds), the drive brakes will be applied and in an emergency stop situation, the VVVF will decelerate immediately to zero, and the brakes will be applied to assist in the deceleration process.

7.5.4 Slew Drive Brake Lifted Switch

The slew drive brake lifted switch indicates that the brake (are operated electro-magnetically transmitting the torque by dry friction) has lifted, and is used to confirm correct operation prior to slew motion. An alarm is raised if it is not detected within two seconds of the PLC output being turned on.

7.5.5 Quadrant Switches 1 to 2

The main function of quadrant switches is to prevent collisions at the change-over point from one quadrant to the next (when both switches from adjacent quadrants are operated). They are used to confirm that the slew encoder is reading a correct value (i.e. +/- 10°) and are activated to indicate which quadrant of slew the boom is in, i.e. 0°- 90° / 90°- 180° / 180°- 270° / 270°- 360°

If the encoder is not within this tolerance range an alarm is to be raised and slew stopped in all modes except the maintenance mode.

7.5.6 Yard Conveyor Slew Protection Limits

This switch stops the slew motion over the yard conveyor if the luff level is not at or above horizontal level (i.e. 0°) to clear the conveyor. T hese two inductive proximity switches (Figure 7-20) are activated in either quadrant X or Y as the slew motion approaches the point where the boom will cross the yard conveyor. The switches are activated continually while slewing over the yard conveyor area. One switch will stop anti-clockwise movement if the luff is not at or above 0° and the other one stop clockwise. An al arm is raised if the slew is stopped at one of these switches and the luff is not at 0° or abov e the boom. Conveyor must stop when the boom is crossing it.

The slew angle and boom position of a machine is determined via two methods:

- A single absolute encoder driven by the slew gear, and monitored/calculated by the PLC
- Proximity switches to indicate the position of the boom in one of the slew quadrants.

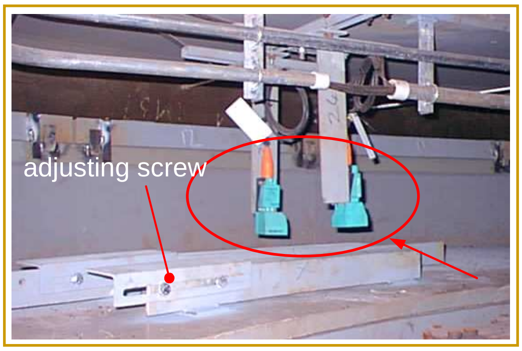


Figure 7-20: Slew protection limits proximity switches.

7.5.7 Slew Multi-Turn Absolute Encoder

The encoder, as shown in Figure 7-21, is driven via a gear set that results in X1 revolutions for the 270° motion. The encoder provides 360 increments per revolution, which results in a slew position of high accuracy.

Figure 7-21: Slew multi turn absolute encoder.

1) "X" depends on gear ratio between the slew drive crown wheel and the pinion of the slew encoder.

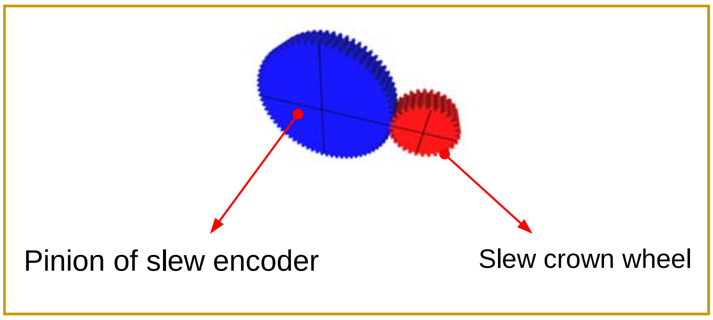


Figure 7-22: Slew encoder gear ration, schematic illustration.

7.5.8 Slew "clockwise" Operational End Limit

This switch indicates whether the slew motion has reached its normal clockwise operational end limit or not (which is beyond the software limit). When activated, it is to stops slew clockwise motion, and an alarm is to be raised.

7.5.9 Slew "clockwise" Emergency End Limit

This lever arm switch is activated by a striker on the slew movement, and indicates when activated, that the slew motion has travelled past the operational clockwise travel limit. If this switch activated, it will cause the VVVF to stop, causing all drives to stop, and raise an alarm. Via local controls, it is possible to slew away from this limit (anti-clockwise), while the emergency end limit override key switch on the LCS has to be operated.

7.5.10 Slew motion slip monitoring

Two inductive sensors, as shown in Figure 7-23, are used for the purpose of slip monitoring between the electric motor and the slew drive gearbox system so that the relative angular velocity of the shaft before and after the multiple disc clutch will be compared. The comparison of the two signals detects the slip. The slip (relative velocity difference) should be smaller than 4 %, otherwise the control unit stops the slew drive.

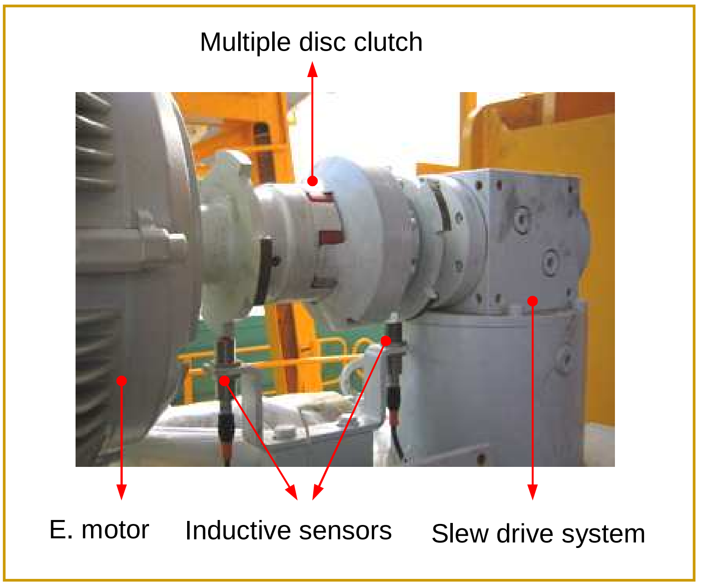


Figure 7-23: Slew drive system - slip monitoring.

7.5.11 Machine To Machine Anti-Collision Sensor

7.5.11.1 General

The machines are controlled automatically and therefore a stockyard machine anti-collision system, as shown in Figure 7-24, is an optimal solution to prevent the collision between the machines travelling in the stockyard.

The system:

- Has a model of the stockyard and the stockpiles
- Always has to know where the machine and it's neighbouring machines are

- Always has to know the current slew angle and long travel position of all machines so that it knows where their boom tips are.

The machines are normally fitted with 2-contact micro wave sensors, which provide the PLC control system with 2 signals:
The first one is when the distance between two machines on the same track is 20 m or less and the second one is when the distance is 10 m or less.
When the 20 meter signal is set off, it raises an alarm and restricts long travel movement in the direction of travel to 6 m/min; if the 10 meter signal goes off, an alarm is raised, and causes a rapid stop of long travel and also issues a signal to the other machine to cause a rapid stop.

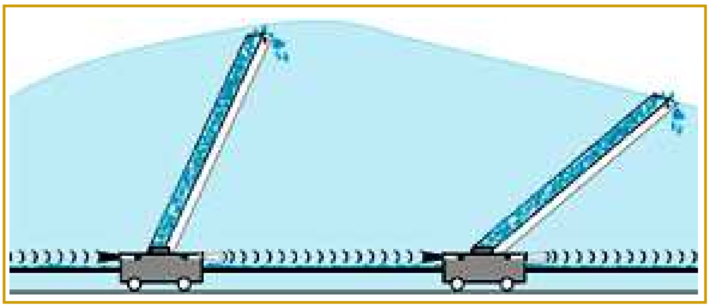


Figure 7-24: Microwave sensors for anti-collision system.

7.5.11.2 Principle of Operation

The sensor used in this system, emits a high powered acoustic wave which is reflected from the body of the machine which its distance being measured. The reflected signal can be processed via software to enhance the correct signal and reject false or spurious echoes. The slave transducer mounted on a fixed position detects the pulse and immediately emits a pulse back to the master on the moving machinery. The sender calculates transit times and gives an out put proportional to the position of the moving machinery in relation to the emitter. The measured distance by the software is used to determine the out put signal (4 …20 mA) and is compared to the relay set points which are already programmed to determine whether or not the relays should be switched or alarms should be raised.
One of the most important advantages of this system is that, there is no wiring required between the master and the slave transducers which allow for easy retrofit to existing stackers and reclaimers.

7.6 LUFF DRIVE SYSTEM

7.6.1 General

The up and down movement (Luff- up/down) of the boom, as shown in Figure 7-25, is fulfilled via two hydraulic cylinders which enable the machine to stack and / or reclaim at different heights.

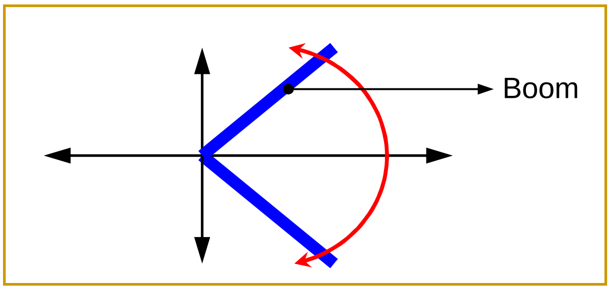


Figure 7-25: Luff motion of the boom (Side view).

7.6.2 Luff- Upper / Lower Limit Proximity Switch

These two inductive sensors, (fixed on the structure) with the help of a metal sector (moveable on the luff pivot), as shown in Figure 7-26, indicate that the luff is at its upper / lower limit of travel and inhibits luff up / down motion. The position of this switch is beyond the normal encoder software upper/ lower limit, and if operated stops the hydraulic pump in all modes other than local.

Figure 7-26: Luff- upper / lower limit proximity switch.

7.6.3 Luff at / or Above Zero Degrees (Horizontal Line)

This switch is activated by a striker on the luff pivot, and is activated whenever the boom is at zero degrees (horizontal) or above. The proximity switch is utilized in the slew motion to inhibit slew motion which may cause boom damage due to collision with the yard conveyor or embankments.

7.6.4 Luff Pump Over-pressure Switch

This pressure switch is mounted on the power pack and senses whether the system pressure has exceeded the normal operating range or not. If activated, it stops the pump in all modes, an alarm is to be raised, and stops all reclaiming operations.

7.6.5 Luff Angle Absolute Encoder

There are two kinds of angular measurement devices for encoding the luff angle: absolute and incremental encoders. For a more functional description of absolute encoders please refer to the theory part of this work. Some different encoders are shown in Figure 7-27.

Figure 7-27: Incremental -/ Absolute encoder.

The luff encoder shown in Figure 7-28 is mounted at the luff pivot point, the single turn increment absolute encoder provides the PLC with boom-tip accuracy of +/- 0.05° (+/-100 mm).

Figure 7-28: Luff angle absolute encoder.

7.6.6 Luff Encoder Check and Re-Synchronization

The control unit will check that the encoder output value is increasing when luffing up, and decreasing when luffing down when the pump is running, and directional solenoid is energized. This will light up if the coupling is broken or the encoder is faulty.
If either of the above occurs, luff motion will stop, automatic operations will stop, and an alarm will be raised. To re-synchronize the encoder, “local” mode is to be selected, and the boom is to be raised to luff upper limit proximity switch position.

7.6.7 Luff Cylinder Overload Pressure Transducers (analogue)

These pressure transducers provide the control system with an analogue signal proportional the pressure in the luff cylinders. If an overload situation (boom is resting on the stockpile or ground) is sensed, it will stop the luff down and slew motion, and activate the luff up motion for a minimum of three seconds. If the pressure is still above the normal value after the initial luff up, the three second luff action will be repeated two more times, and if the overload pressure still exists, all automatic operations, all drives will stop, and an alarm is to be raised.

7.7 HYDRAULIC SYSTEM (Lubrication)

7.7.1 Hydraulic Power Pack Oil Level Switch

This switch indicates the level of fluid (hydraulic oil) in the hydraulic tank. There are two kinds of oil level switches in the tank for more safety and accuracy. One of them is the high level switch which indicates that the lubrication storage is full. When activated, it turns off the re-filling solenoid, and turns off the “fill” light. Low level switch is the other one which indicates if the lubrication storage is low and requires re-filling. An alarm is to be raised when this switch activated.

7.7.2 Line “A” / “B” “End of Line” Pressure Switch

This cycle complete switch detects that flow and pressure has been detected at the end of the line “A” lubrication line (Figure 7-29). When activated, it indicates the cycle is completed for line “A”, and turns off line “A” solenoid, and turns on line “B” solenoid
after 2 minutes. An alarm is to be raised if the pump “A” cycle has been active for 8 minutes and no flow or pressure has been detected. The same whole process is the same for line “B”.

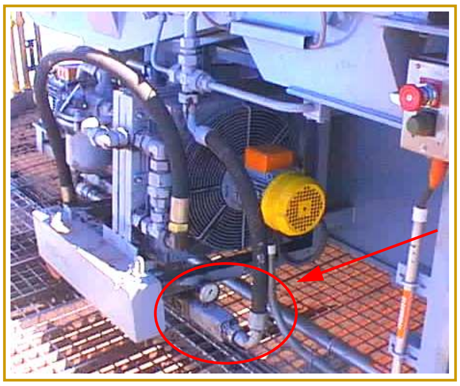


Figure 7-29: Bucket wheel oil flow meter.

7.7.3 Hydraulic Power Pack Temperature Switch

It is very important to hold the hydraulic temperature in different climate conditions almost constant. Thin oil (with a low viscosity) in high temperatures is as bad as thick oil (with a high viscosity) in low temperatures. A temperature switch is designed to keep the oil temperature in a range recommended by the company to achieve a high efficiency. This switch contains three separate contacts:

- Low… this switch turns on the oil heater, when activated
- High… (70 ℃ or above) this switch starts the power pack cooling fan[1], when activated, which will continue to run for a period of 3 minutes until this switch is no longer activated.
- High/High… (75 ℃ or above) when activated, indicates the oil temperature is extremely high and will stop all automatic operations, an alarm is to be raised.

1) The temperature sensor also starts the cooling fan when the oil temperature is at or above 40 ℃ and when oil temperature decreases to 35 ℃ or below, it stops the cooling fan.

7.7.4 Hydraulic Power Pack Tank Flap Switch

This switch, when activated, indicates the suction line to the pump is "open" (i.e. flow allowed). When not operated, the pump and auto operations will stop, and an alarm is to be raised.

7.7.5 Boom Conveyor Bearing Lube Flow Switch

The bearing lubrication flow switch indicates lubrication flow to the bearing, and if not operated for a few seconds, an alarm is to be raised to indicate no oil flow to the bearings. With the help of a switching box, the oil flow to different parts can be control for lubrication purposes.

Oil does not flow to the bearing → the relevant plunger goes backward → proximity switch opposite the plunger gives a signal → it takes more than few seconds → an alarm is to be raised. These oil flow switches are mainly for the head and tail pulleys on both sides (right and left).

7.7.6 Boom conveyor G-Box input shaft bearing lube flow switch

This flow switch indicates lubrication flow to the bearing, and if not operated when the Line "A" solenoid and pump has been operating for about 5 seconds, raises an alarm to indicate no flow in the line.

7.7.7 Boom conveyor head- / tail pulley lube flow switch (Left / right)

These flow switches indicate lubrication flow to the bearing, and if not operated when the Line "A" solenoid and pump has been operating for about 5 seconds, raises an alarm, to indicate no flow in the line.

7.7.8 Bucket wheel G-Box input shaft lube flow switch

This flow switch indicates lubrication flow to the bearings of the bucket wheel, and if not operated when the Line "A" solenoid and pump has been operating for 5 seconds, it raises an alarm to indicate no flow in the system.

7.7.9 Bucket wheel shaft lube flow switch (drive- /non-drive side)

These flow switches indicate lubrication flow to the bearing, and if not operated when the Line "A" solenoid and pump has been operating for 5 seconds, raises an alarm, to indicate no flow.

7.7.10 Bucket wheel shaft, non-drive side lube flow switch

This flow switch indicates lubrication flow to the bearing, and if not operated when the Line "A" solenoid and pump has been operating for 5 seconds, raises an alarm, to indicate no flow.

7.7.11 End of line slew Bearing flow switch Line A / B

This flow switch detects that there is flow at the end of the line A/B lubrication line. When activated, it indicates the cycle is completed for line A/B, and turns off line A/B solenoid, and turns on line B/A line solenoid an alarm is raised if the pump A/B cycle has been active for 8 minutes and no flow has been detected.

7.7.12 Fill indicator

This indicator light at the re-filling point is illuminated when low level is detected, and turns off, when high level is detected. It flashes when the "fill" solenoid is energised.

7.7.13 Pressure Switch

There are two types of pressure switches used here:

- Diaphragm pressure switch (low pressure)
- Piston pressure switch (high pressure)

The switches are pre-triggered via a spring with the possibility to change the spring characteristic (switching point can be set by an alteration to the spring constant).
Good repeatability, high pressure, low hysteresis are the most important characteristics of these pressure switches.

7.8 BUCKET WHEEL (BW)

7.8.1 General

A bucket wheel, as shown in Figure 7-30, is used in reclaimers to reclaim the material from the stockpile and throw it through the chute onto the conveyor belt for further transportation. In this chapter different sensors and switches mounted on the bucket wheel will be described.

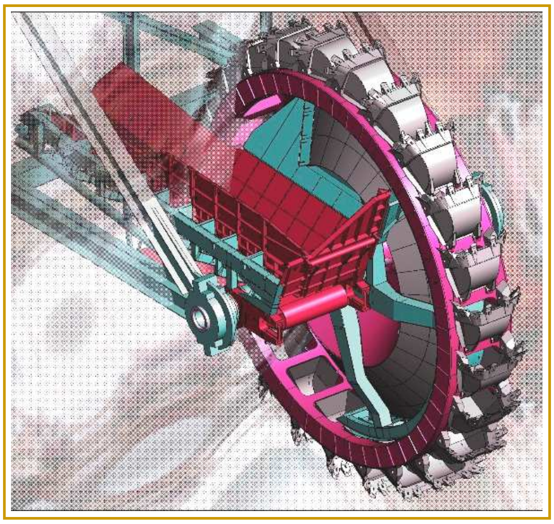


Figure 7-30: Bucket wheel.

7.8.2 BW Under-Speed Sensor

This proximity switch, mounted on the bucket wheel assembly, senses if the rotational speed of the bucket wheel is within 90% of the e.g. 5.5 RPM speed. If the speed is not sensed correctly, an alarm is to be raised. If the speed falls below 90% of the 5.5 RPM reclaim speed, it indicates the bucket wheel is becoming blocked.

7.8.3 BW Maintenance Locking Pin in "STORED" Position

This proximity switch indicates that the bucket wheel locking pin (a pin used for preventing the bucket wheel movement during the maintenance period) is in "stored" position, and if it is not sensed, the bucket wheel and all associated drives are inhibited. An alarm is to be raised in all modes other than local, if this is not on.

A large disc with some holes on it fixed to the bucket wheel is used for this purpose where the holes are used also, with the help of inductive sensors, for slip monitoring of the bucket wheel.

7.8.4 BW G-Box Selection Lever in "Main Drive" Position

This switch indicates that the gearbox drive selection lever is in the MAIN DRIVE position. When in this position, the maintenance drive is inhibited in all modes.

7.8.5 BW G-Box Lever in "MAINTENANCE" Position

This switch indicates that the gearbox drive selection lever is in the MAINTENANCE position. When in this position, the main drive is inhibited in all modes. The selection lever for the MAIN and MAINTENANCE positions is mounted on the bucket wheel gearbox as shown in Figure 7-31.

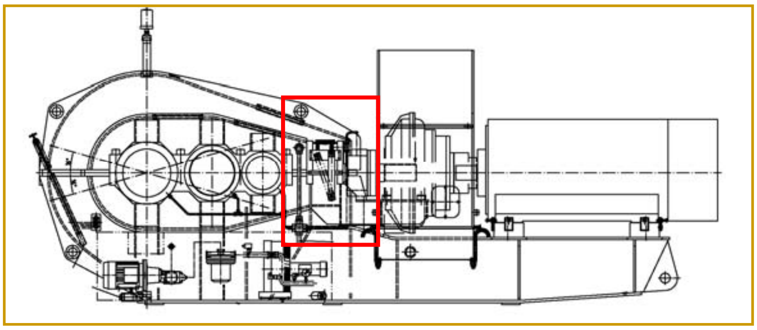


Figure 7-31: Bucket wheel gearbox selection lever.

7.8.6 BW Gearbox Oil Flow Switch

7.8.6.1 General

The gearbox oil flow switch (Figure 7-32) confirms that oil flow has been sensed when activated and monitors it via a control monitor (Figure 7-33) and detects whether a preset flow value is reached or not and provides a switching signal. It is checked 5 seconds after the oil pump is started. If no pressure is sensed, the main and maintenance drives are inhibited from starting, and an alarm is to be raised.

Temperature range of the medium: -20 ... +60 ℃

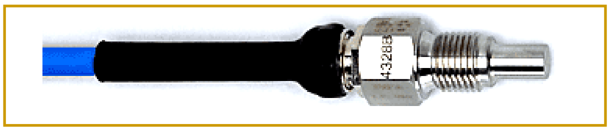


Figure 7-32: Gearbox oil flow switch.

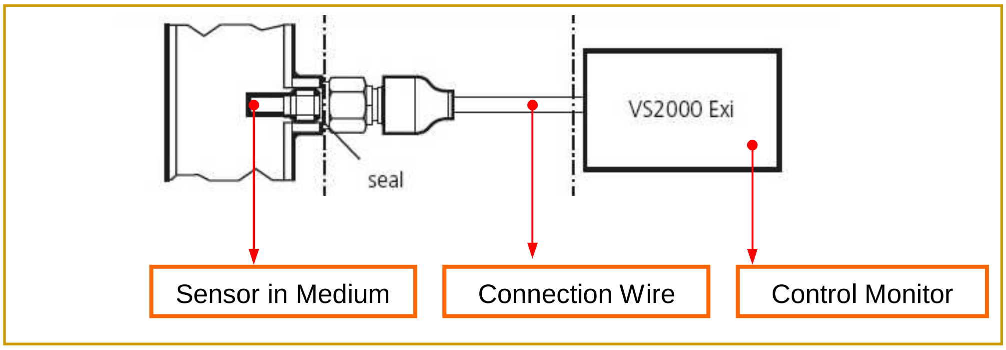


Figure 7-33: Connection of control monitor to the sensor.

Permissible operating temperature range at the mounting location and maximum temperature range of the medium: -20 ... +60 ℃

7.8.6.2 Installation of oil flow switch

The sensor tip must be completely immersed in the medium. In the case of horizontal pipes (Figure 7-34, left) the unit is mounted from the side, if possible, for vertical pipes (Figure 7-34, right) the unit is mounted in a place where the medium flows upwards. When the unit is to be mounted at the bottom of the pipe, it should be free from deposits. When the unit is to be mounted at the top of the pipe, it should be completely filled with the medium to be monitored.

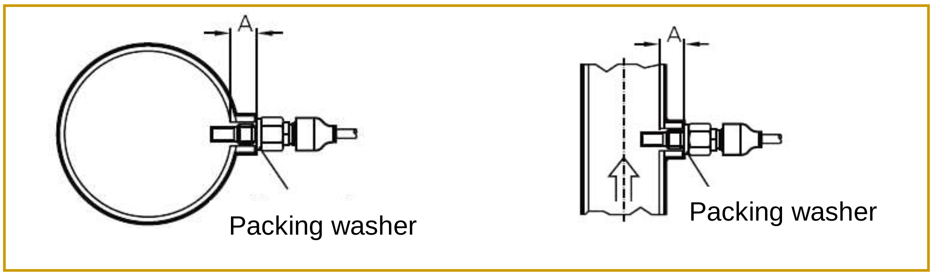


Figure 7-34: Oil flow switch in horizontal (L) and vertical pipes (R).

7.8.7 BW Fluid Coupling Over-Temperature Limit Switch

7.8.7.1 General

The electric drive motor (with constant speed) rotates the bucket wheel gearbox with the help of a fluid coupling (Figure 7-35) which provides a smooth start-up and absorbs the shocks.

Figure 7-35: Hydraulic coupling between the motor and the gearbox.

The principle of hydrodynamic power transmission is based on the interaction of a pump and a turbine. This principle is realized by two bladed wheels (an impeller which is connected with the driving machine, and turbine wheel which is connected to the output shaft) together with a surrounding shell, these bladed wheels form the working chamber in which the operating fluid circulates. As a result of the movement of these wheels, the operating fluid is circulated and mechanical power is transmitted from the pump to the turbine.
The transmission of power itself occurs wear-free and the only parts that are subject to wear are the bearings and seals involved in the process. In Figure 7-36 a fluid coupling is shown at rest, at start up as well as in full operation.

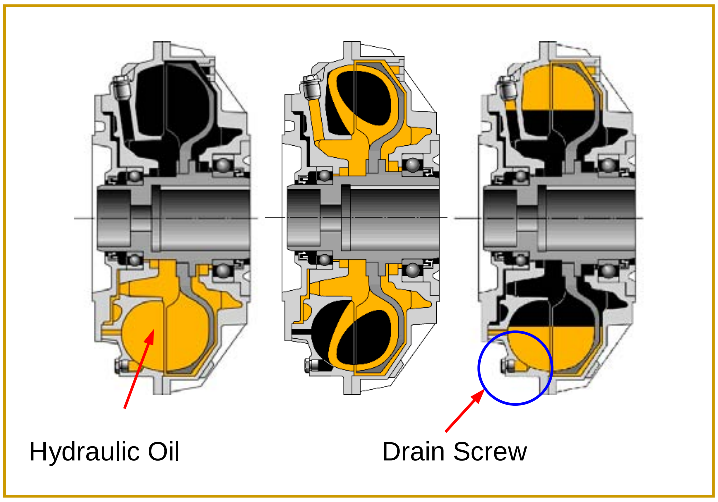


Figure 7-36: Bucket wheel fluid coupling.

Oil temperature monitoring is very important for the system's effectiveness. Therefore an over-temperature switch is mounted at the coupling. If the over-temperature plug of the fluid coupling is operated, this switch will be activated. The bucket wheel main / maintenance drive will stop and an alarm goes off.
There are two possibilities for the temperature monitoring:

BTS: Non-contacting Thermal Switch, which is used in systems with a speed of more than 1200 rpm and therefore is not practical in this case.

MTS: Mechanical Thermal Switch (needs to be replaced after switching operation).

High oil temperature can be a signal for bucket wheel slippage. In case of slip, the temperature of oil in the hydro-coupling raises and the reaction of the thermal switch has the benefits of some possibilities such as: Temperature warning, switch-off of drive motor, reduction of engine speed or reduction of load on the driven machine.

7.8.7.2 Function Principle

A spring-loaded pin and a chamber filled with solder are integrated into the switching element. The response temperature of both the switching element and the solder are the same. When the response temperature is reached, the solder releases the pin and it is pushed outside via the compression spring. The pin actuates the switching finger, illustrated in Figure 7-37 (the switch is provided with a pivot able switching finger) causing the switch to switch over.

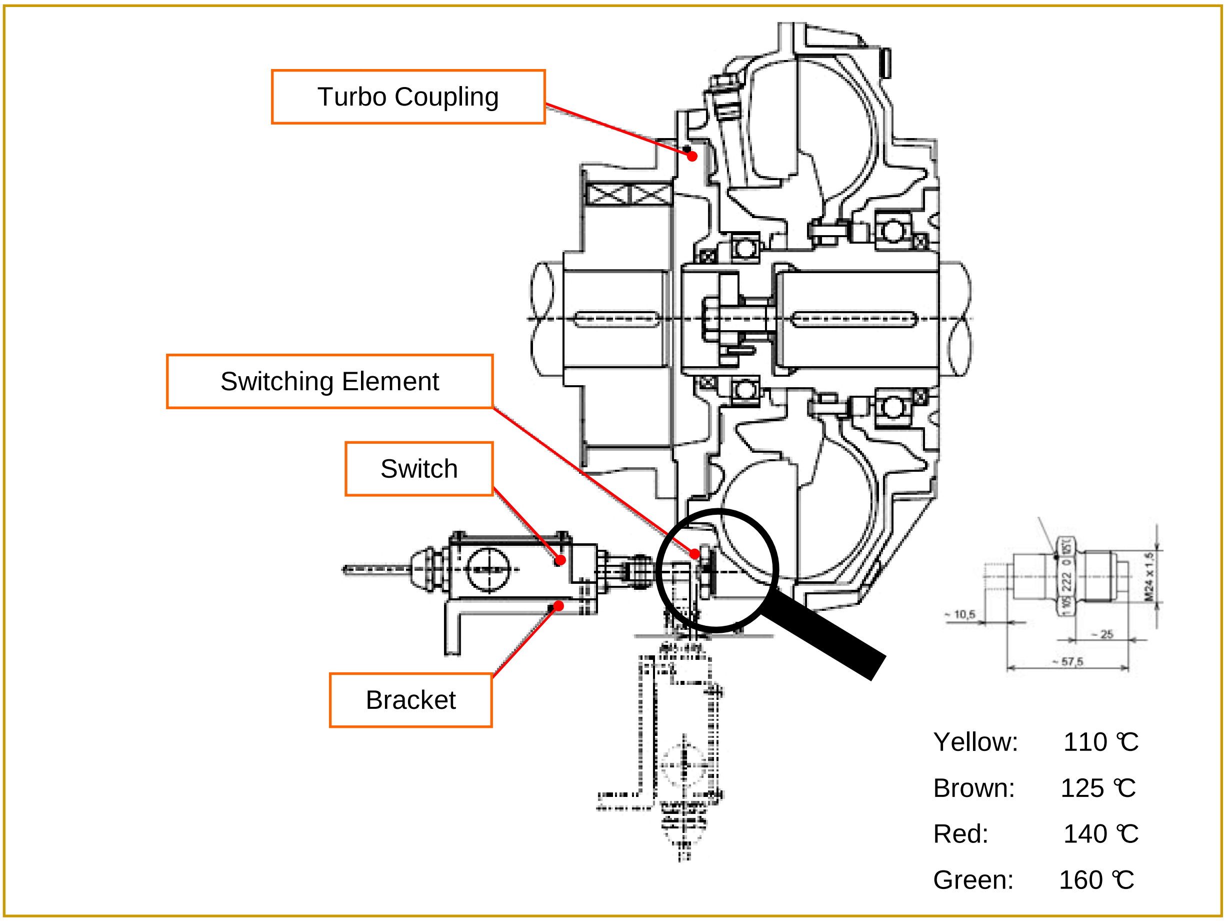


Figure 7-37: Bucket wheel fluid coupling switching element.

The Figure 7-38 shows the axial and radial installation of the switching element and the switch.

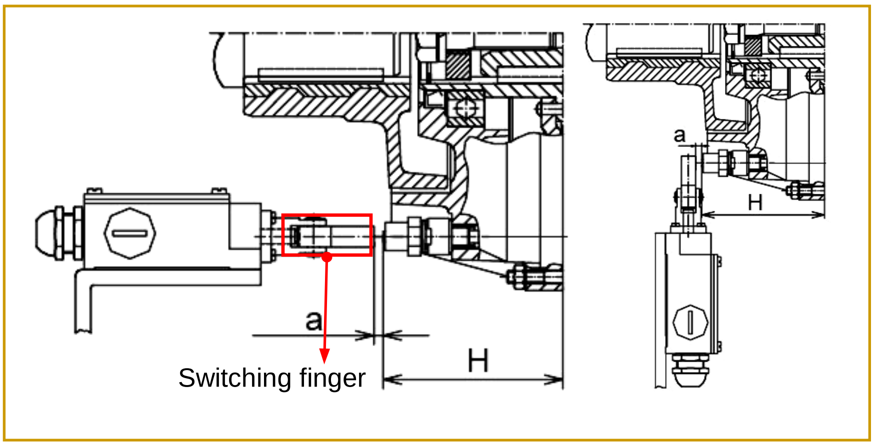


Figure 7-38: Axial and radial installation of switching element and switch.

7.8.8 BW Gearbox Oil Pressure Switch

This switch confirms that the oil is circulating continuously within the gearbox, and if not sensed for five seconds when gearbox pump running, it stops the bucket wheel and an alarm is to be raised.

7.8.9 BW Gearbox Oil Filter Differential Pressure Switches 1 & 2

7.8.9.1 General

This switch indicates if the filter in the gearbox pump circuit is blocked, and it raises an alarm if activated. If one filter is blocked, the second filter can be selected by operating a mechanical valve at the gearbox.

7.8.9.2 How to measure the Filtration Efficiency

Beta ratio:

$$\beta x = (n_{in} = X\mu m) : (n_{out} = X\mu m) \tag{7.4}$$

Where "n" is the number of particles = x µm upstream and downstream from the filter.

Max. working pressure: 2 MPa (20 bar)
Bursting: 6 MPa (60 bar)
Bypass Valve: 170 kPa (1, 7 bar)
Working Temperature: -25…+110 ℃

7.8.10 Torque Load Cell (Load Measuring Pin)

7.8.10.1 General

The load-measuring pins, shown in (Figure 7-39), are designed for many diverse applications such as direct replacements for clevis or pivot pins. In this case they are used for protection of the bucket wheel drive. If the torque in any mode is seen above approx. 1.6 times nominal torque, for a period of approx. 10 seconds or longer, the drive will stop, and an alarm is to be raised. They have many advantages to other load sensors: that they do not normally require any change to the mechanical structure and they are typically used in rope, chain and brake anchors, etc.

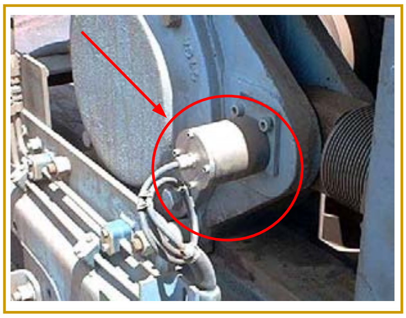


Figure 7-39: Torque load cell.

Description:

A load measuring pin senses the force applied across it, with the help of strain gauges installed within a small bore through the centre of the pin. "Two grooves are machined into the outer circumference of the pin to define the shear planes, which are located between the forces being measured. The Pins are manufactured from special stainless steels, fitted with welded or "O" ring sealed end caps and with special attention to the signal cable glanding, a very high operating reliability can be guaranteed even for load pins operating in rough weather conditions [19]".

7.8.10.2 Locking System Load Rating and Dimensions

A load-measuring pin needs to be securely locked into position, both in the axial and rotation modes, to ensure that accurate and repeatable results are obtained from the system. A standard load pin is designed to sense the force in one direction only (Figure 7-40). A force at right angles to that force will produce a zero output from the sensor.

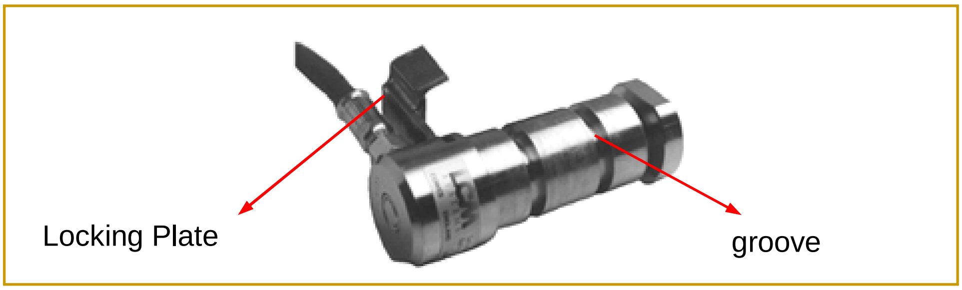


Figure 7-40: Load cell.

The following table makes a comparison between the lowest and the highest rating and their dimensions.

Ø D [mm]	L1	Rating (Tones)
25.00	100	2.5
75.00	225	50

Table 7-1: Load cell rating.

A typical load measuring pin with acting forces are shown in Figure 7-41.

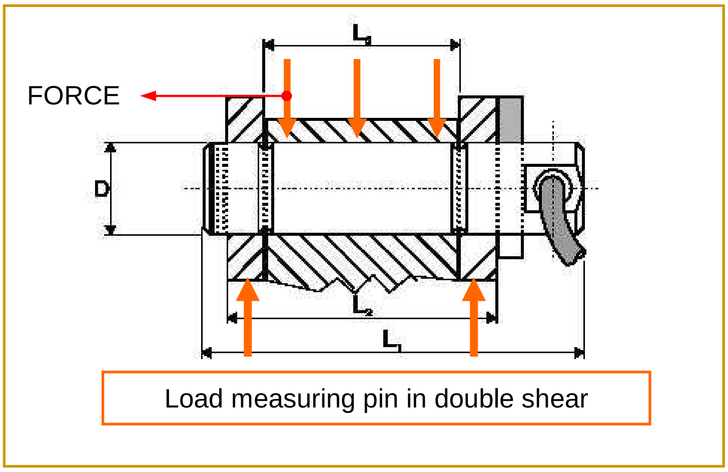


Figure 7-41: Load measuring pin with acting forces.

7.9 Dust suppression system

7.9.1 General

The water system equipment installed on the machine operates in high dust concentration (coal, sulphur and limestone handling) areas.

“Fresh filtered water (max. 0,5mm) is delivered over a hose reeler on the machine with Q=500l/min [20]”. The spray bars are controlled by solenoid-valves and the water supply for the dust suppression is distributed from the hose reeler mounted on the portal structure. Water sprays will only operate if water pressure is present at the hose reeler.

Water spray/solenoids are located at the following locations (Figure 7-42):

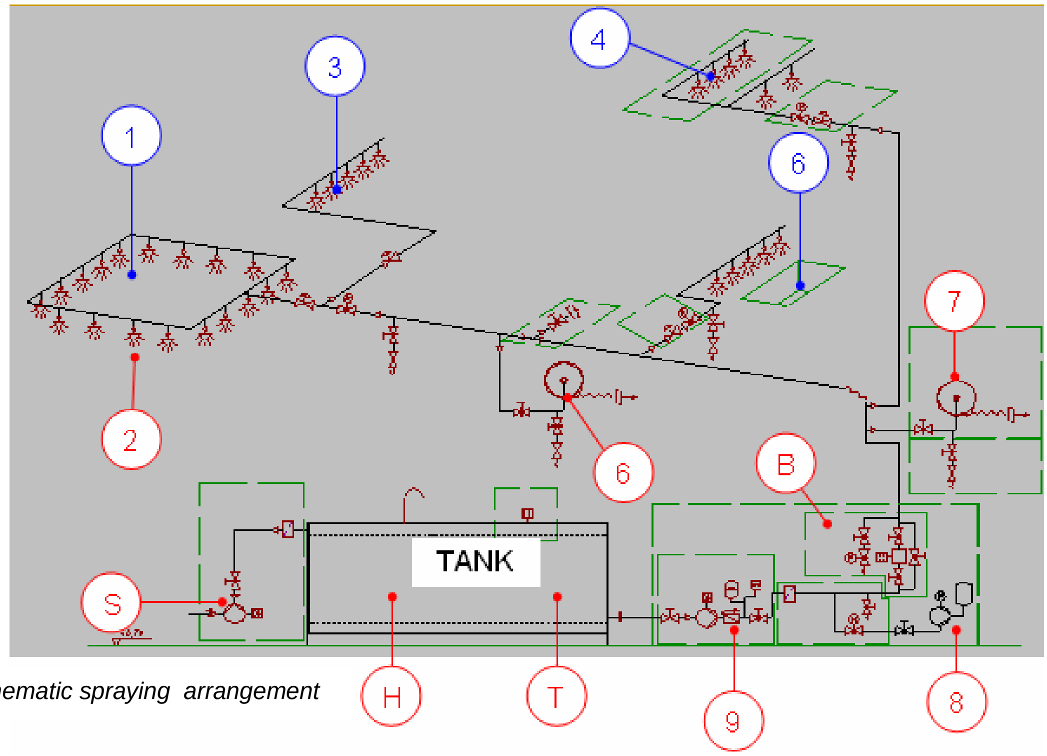
- bucket wheel discharge transfer chute
- bucket wheel area, stockpile sprays
- at the boom conveyor transfer chute
- yard conveyor transfer/loading table area

7.9.2 Function description of the control system

Water supply is provided over an open water channel that runs parallel to the rail. The water is pumped into a water tank (equipped with a water level) over a suction pump. The tank is equipped with 2 screw-type heating elements for frost protection, and that are monitored by a resistance thermometer.

7.9.2.1 Flow measurement

The flow measurement used in the dust suppression system sends a signal (4-20 mA) to the primary control system. The device has a digital display on which the flow rate can be read directly in terms of m³/h.



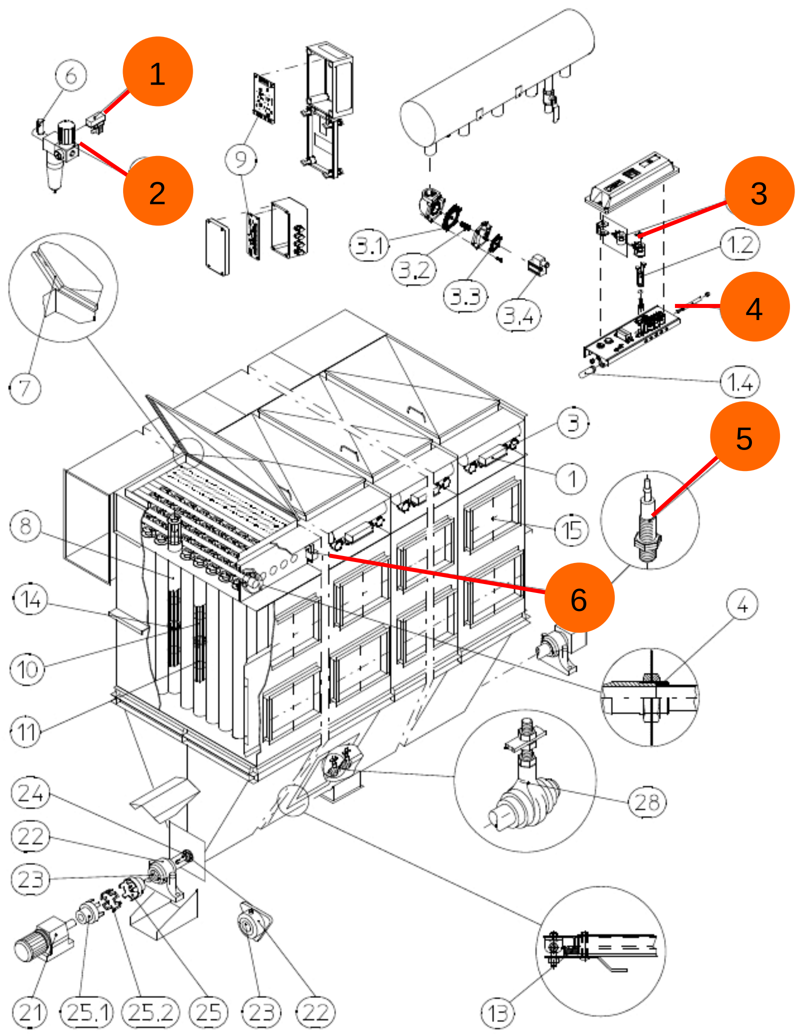
Schematic spraying arrangement

1	Spray bars; discharge at boom head	8	Compressor
2	Spray nozzle with ball joint	9	Manometer
3	Spray-Headers; discharge at boom head	T1	Resistance thermometer
4	Discharge chute	H1,2	Heating bar
5	Feed table boom conveyor	9	Suction pump unit
6	Hose reeler	S	Suction pump unit
7	Hose reeler on tripper car	B	Booster pump unit

Figure 7-42: Dust suppression system.

7.10 Dedusting system

In some situations a dedusting system (Figure 7-43) must be used to control the amount of dust and other pollutions in the surroundings. Sometimes we reduce the particles only to decrease the wearing phenomena, sometimes we reduce it to achieve a clean environment and in some situations we need both of them. In the following chapter the sensorics of dedusting system will be described.



1	Pressure switch	4	Heating element with thermostat
2	Manometer	5	Proximity switch
3	Coil for solenoid valve	6	Differential pressure transmitter

Figure 7-43: Dedusting system.

By assembling a safety switch on inspection and maintenance doors, the whole system is automatically switched off when a door is opened.

7.10.1 Filter function

The crude gas enters into the filter and is distributed among the filter bags. At the same time the coarse dust particles drop directly into the dust collecting hopper. On the outside of the filter bags, which are put on support cages the dust is hold back, while the clean gas leaves the inside of the filter bags via injector nozzles into the clean gas chamber. After a preset cycle time an electronic control unit opens a solenoid valve for about 0.08 sec. Compressed air streams via jet pipes into the injector nozzles. Thus the normal flow direction of the air is reversed, air from the clean gas chamber is dragged along, the bags blow up immediately and the dust drops. The filter bag row is again in filtering position after this short cleaning impulse.

7.10.2 How the compressed-air monitor works

“When a diaphragm valve opens, the pressure in the reservoir drops briefly. A pressure sensor (Figure 7-44) measures this signal at the reservoir and converts it into a current signal that is forwarded to the control unit. The control unit compares this signal with a preset monitoring threshold level, which has to be undershot for a brief time. The system monitors opening and closure of the diaphragm valve and monitors the compressed-air system for leaks” [21].

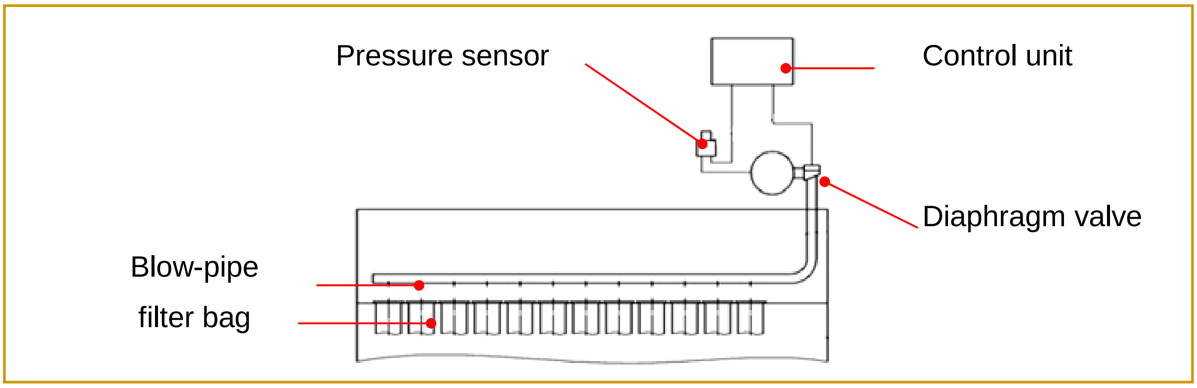


Figure 7-44: Compressed air monitoring.

7.10.3 Bag-breakage monitor

A monitor device is installed in the clean gas pipe which converts the measured dust content into an electric signal that is forwarded to the control unit. The control unit compares this signal with a preset threshold level, and displays an alarm if the threshold level is overshot.

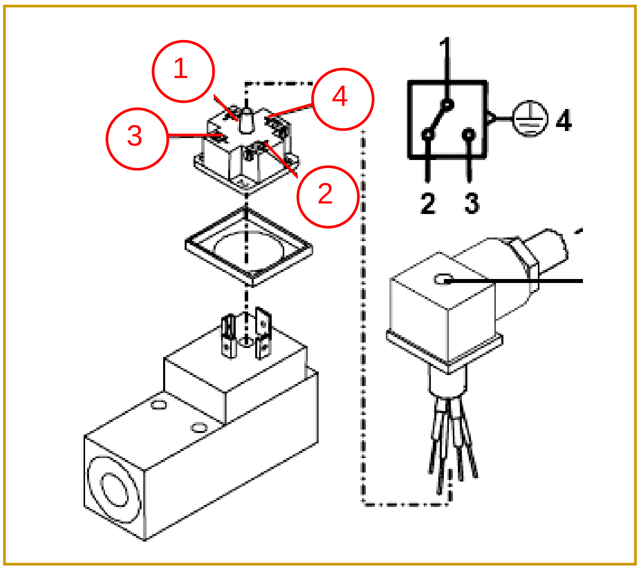
7.10.4 Differential Pressure Transducer

The differential pressure transmitter (two- wire transmitter) is built up of a compensated, calibrated and piezo-resistive measuring bridge, together with a voltage regulator bridge amplifier and voltage to current converter, and is used for monitoring the possible contamination in the system.
The differential pressure transducer works with a supply voltage of 16 to 32 VDC and with an output signal of 4 – 20 mA pressure proportional.

7.10.5 Pressure switch

Pressure switch (Figure 7-45) opens or closes an electric circuit when a set pressure value is reached. The rise in pressure causes a force to be pressed against the plunger. The adjustable spring pre-tension causes a counter force. If the spring force is exceeded, the plunger will actuate a micro switch which opens or closes the electric contacts. If the dew point is reached, the membrane will ice up and become stiff and the dew point can be lowered if dried compressed air is used.

Adjustable switching pressure: 1 – 12 bar
Permitted switching frequency: maximal 3, 3 Hz
Maximal switching current: 5 A (ohmic load)



1	Switching voltage *AC: 0 … 250 V* *DC: 0 … 125 V*
2	Open output
3	Close output
4	Earth

Figure 7-45: Pressure switch for dedusting system.

7.10.5.1 Level limit switch

A level limit switch (Figure 7-46) is normally screwed into the lateral container wall (of the hopper or silo) so that it is level with the filling height to be registered and monitored. A brushless synchronous motor (which is freely suspended within the housing) drives a rotating measuring vane. When the material level reaches the measuring vane, it is handicapped its rotation. The caused reaction torque is used to operate the micro switch giving a signal output and to stop the motor. Due to falling material level, the paddles becomes free again, a spring draws the motor back into his operating position, the micro switch returns to his initial position and the motor switched on. The output signal is switched back.

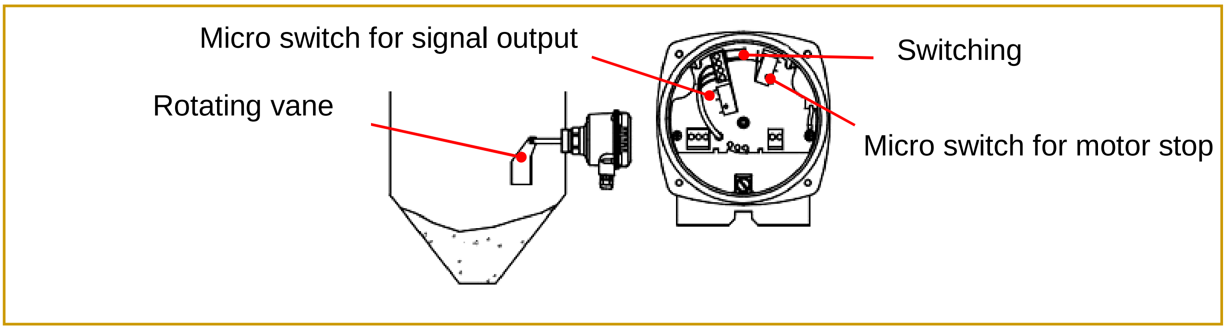


Figure 7-46: Level limit switch for dedusting system.

7.11 Central Lubrication - Superstructure

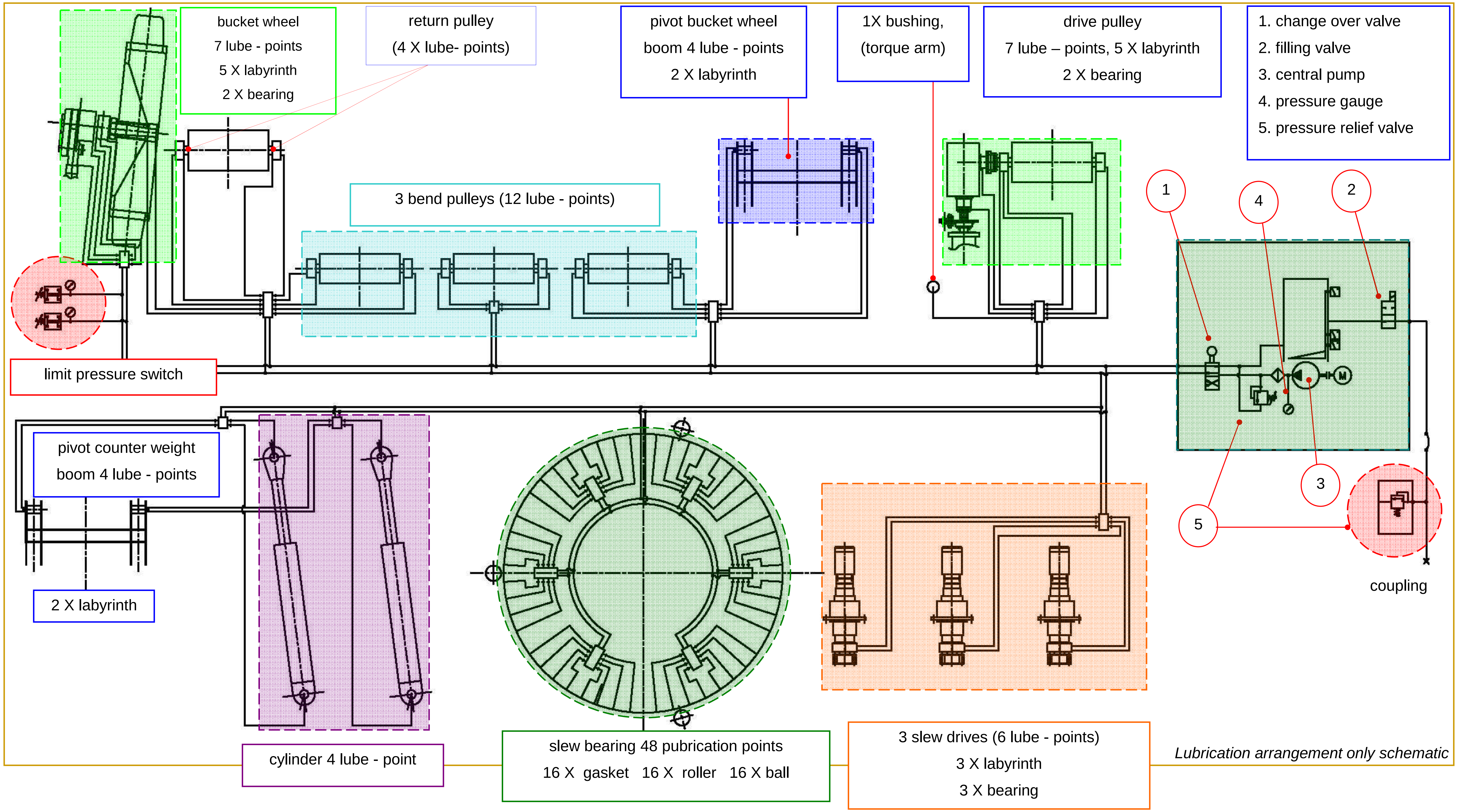


Figure 7-47: Lubrication system.

7.11.1 Lubrication Units

Two independently operating lubrication systems are installed at the machine – both being dual-line and fed from identical lubrication units.

Unit 1: Central lubrication tripper car & long travel bogies

This unit is mounted on the tripper car platform and feeds all lubrication points of the long travel system, including the main pin and the lubrication points of the tripper car belt equipment (e.g. pulleys and the belt lifting device).

Unit 2: Central lubrication superstructure

This unit is mounted on the slew deck, and feeds all lubrication points on the slewing structure of the stacker including the slew bearing, pulley bearings, the drive gearbox output shaft labyrinths, discharge boom pivots, luffing cylinders, bucket wheel bearings and belt tensioning device lubrication points.

7.11.2 Functionality

Control and monitoring of the operation of the grease lubrication system happen by the PLC mounted on the machine. The PLC provides a 48 VDC output to the hydraulic power pack, which provides oil flow to operate the grease pump. An oil pressure switch is provided on the power pack to monitor the operating oil pressure of the unit. Should the unit not reach operating pressure, the PLC will deactivate the power supply to avoid any damage to the unit and provide a system output alarm. When the oil flow is provided from the power pack a voltage out put is pulsed at 1 sec intervals to the oil control valve mounted on the power pack. The valve allows oil to flow from the top and bottom of the grease pump oil cylinder to reciprocate the grease pump.

7.11.3 Low level switch

A grease low-level switch is provided on the grease reservoir to prevent the system from operating when the grease reservoir is empty.

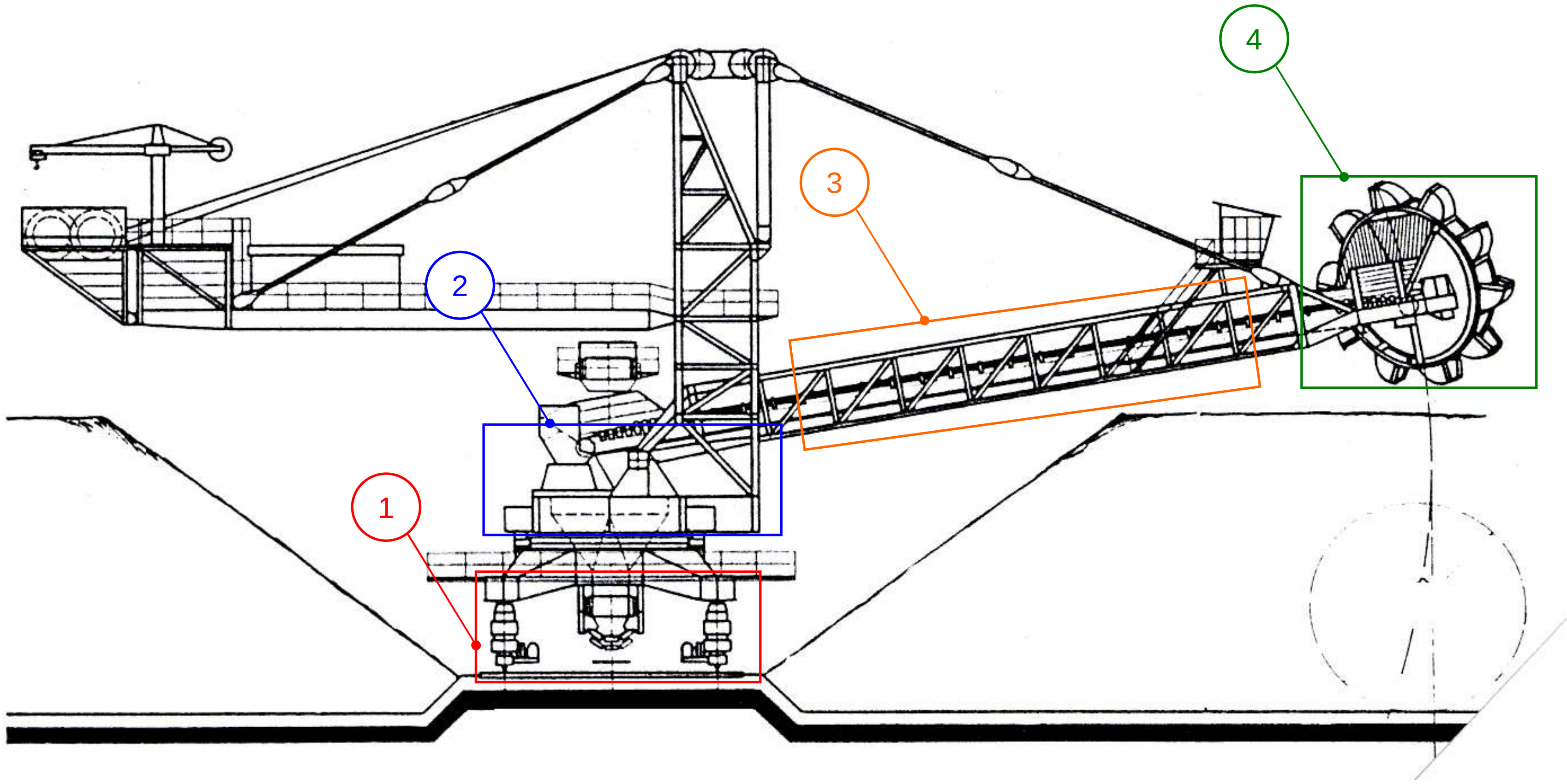
7.11.4 High-level shut off switch

A grease high-level shut off switch is installed to enable the grease reservoir to be filled remotely through an electric isolation valve to prevent the reservoir from being over filled.

7.11.5 Grease pressure gauge

The pressure gauge is installed at the further-most point from the pump station to monitor the grease pressure for each line. This will allow visual and electrical monitoring of the system to ensure correct operation and detection of faults with in the system.

7.12 Sensor Positioning for Reclaimer



1. Long Travel Drive System / Chute System

1) Boom conveyor blocked chute tilt switch
2) Storm locking anchor
3) Lube pressure switch
4) Travel absolute encoder
5) Drive brake lift switch
6) Travel emergency end limit (East / West)
7) Travel operational end limit (East / West)

2.1 Slew System

1) Counter clock wise end limit
2) Slew emergency end limit
3) Slew operation clock wise end limit
4) Slew operation ccw end limit
5) Slew yard conveyor protection
6) Slew absolute encoder
7) Quadrant 1-4 limit switches

2.2 Luff System

1) Luffing upper end limit
2) Luffing lower end limit
3) Luffing above zero degree limit
4) Luffing absolute encoder
5) Luff oil temperature transducer
6) Luff oil level transducer
7) Luff oil pressure Transducer
8) Luff pressure / return line filter blocked

2.3 Cable- / Hose Reeler

1) Cable reel full switch
2) Cable reel empty switch
3) Over tension left / right limit
4) Under tension left / right limit

3. Boom Conveyor

1) BC under speed switch
2) Pull wire switch
3) Belt misalignment switch
4) Belt healthy sensor
5) BC break lift limit
6) BC oil temperature sensor
7) BC coupling temperature
8) Belt scale

4. Bucket Wheel

1) BW under speed switch
2) BW coupling temperature
3) BW temperature sensor
4) BW maintenance locking pin in STORED position
5) BW gearbox selection lever in MAIN DRIVE position
6) BW gearbox selection lever in MAINTENANCE position
7) BW gearbox oil flow switch
8) BW gearbox oil pressure switch
9) BW gearbox oil filter differential pressure switches 1 & 2
10) Torque load cell

Dust suppression system

1) Pressure switch
2) Level limit switch
3) Differential pressure transmitter

Dedusting system

1) Pressure switch
2) Manometer
3) Thermostat
4) Inductive proximity switch
5) Differential pressure transmitter

Lubrication system

1) Low level switch
2) High level shut off switch
3) Grease pressure gauge

Others

1) Anemometer
2) Cable tension sensor

Figure 7-48: Sensor positioning for reclaimer.

8. PROBLEM TREATMENT

8.1 General

In this part of the thesis, possibilities for two problem treatments will be discussed and finally the solutions will be examined and defined. Namely:

- bucket wheel slip monitoring
- collision protection between the boom and the stockpile
- 3D scanning of the stockpile via laser will be also shortly discussed

8.2 Bucket wheel slip monitoring

The slip value of the bucket wheel can be measured directly at the hydraulic coupling but it doesn't deliver correct values in different working conditions because of the dependency of the slip value to the present oil volume in the coupling. The (Figure 8-1) shows the power train (arrow) from the electric motor over the hydraulic coupling to the bucket wheel gearbox.

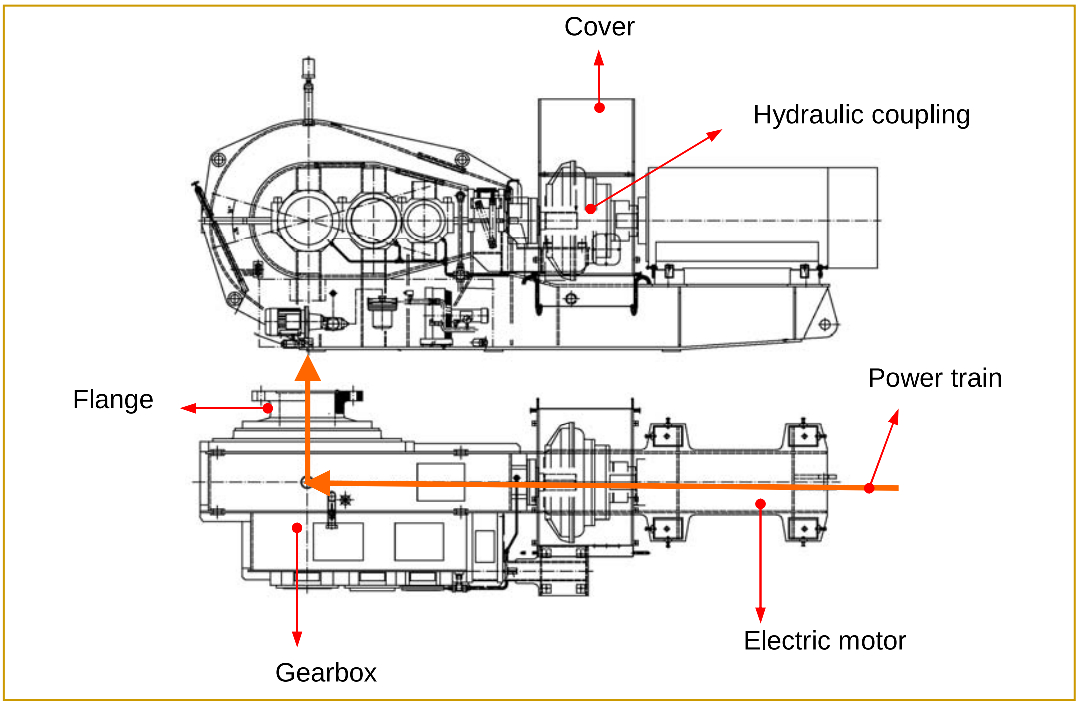


Figure 8-1: Power train motor-coupling-gearbox.

8.2.1 Solution

The slip monitoring of the bucket wheel can be carried out with the help of two inductive proximity switches and a frequency current converter with trip value monitoring and slip signaling which provides the following functions:

- frequency measurement
- slip monitoring
- rotation direction monitoring
- synchronization monitoring

The two inductive proximity switches which are mounted face to face to the bolts of the coupling (front and back side of the coupling) as shown in Figure 8-2 (a) give signal to the frequency converter. The device processes two input frequencies up to a maximum of 1 kHz. The slip is calculated from the two input frequencies (measured within the time window) at channels 1 and 2.

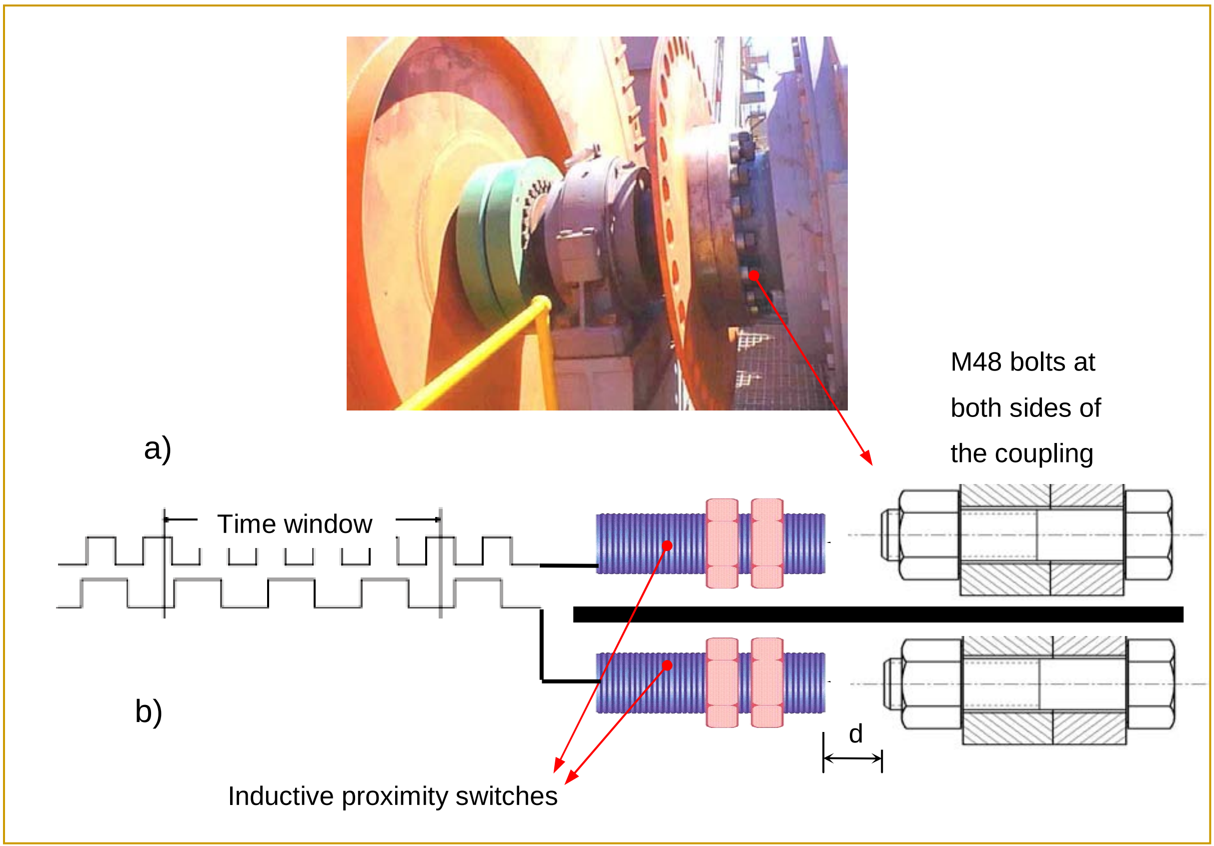


Figure 8-2: Bucket wheel slip monitoring.

If the freely permissible trip value is exceeded, the respective output switches.

The slip value is defined as:

$$Slip = (1 - \frac{frequency \quad channel \quad 2}{frequency \quad channel \quad 1}) \cdot 100\% \tag{7.5}$$

The following table (Table 8-1) gives an overview for some technical data of the relevant inductive proximity switch shown in Figure 8-3.

Switching element function	NC (normal closed)
Rated operating distance (d)	15 mm
Assured operating distance	0…12.15 mm
Nominal voltage	8 V
Switching frequency	0…500 Hz
Hysteresis	1…15 typ. 6 %
Measuring plate not detected	Min. 3 mA
Measuring plate detected	≤ 1mA
Indication of the switching state	LED, yellow
Ambient temperature	-25…100 ℃
Connection type	2m, PVC cable
Core cross section	0.75 mm^2
Housing material	High grade steel
Sensing face	PBT
Protection degree	IP67

Table 8-1: Technical data for inductive proximity switch.

Figure 8-3: Inductive proximity switch with circuit connection.

8.3 Stockpile Volume Measuring via Laser Scanner

The volume of a stockpile can be measured by scanning it via a laser scanner. This procedure can be fulfilled if the scanner moves with a constant angle and velocity over the stockpile and on the other hand presence of a surrounding medium like a wall in background or a container in necessary. Otherwise this can be achieved with the help of two scanners mounted parallel to each other. In our case it is impossible to make these conditions.

Also scanning could deliver only a 3D model (by using a PC) from the bulk goods, which is not interesting to be explained in this work (Figure 8-4).

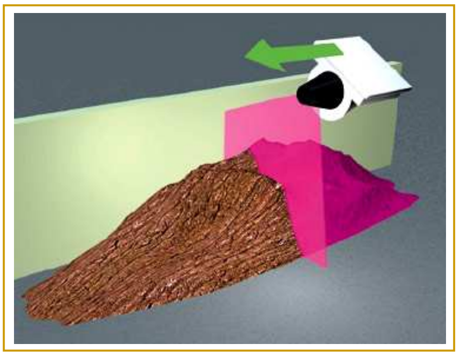


Figure 8-4: 3D laser scanner.

8.4 Laser Collision Protection System for the Conveyor Boom

8.4.1 General

The goal is to analyze and compare different possibilities and solutions for collision protection between the boom and the stockpile on the bulk materials handling machinery (stacker/reclaimer).

The stacking or reclaiming of the bulk material at or from the stockpile will be carried out with the help of a 40 to 60 meter long boom as shown in Figure 8-5.

As the stockpile grows the boom luffs up. The boom is not allowed to come in contact with the stock pile during its luffing or slewing motion. Although the following working conditions shall be take into account to get an optimal solution.

- The machines work in a dusty working area (influence of dust on sensors and equipment)
- The machines work around the clock (influence of brightness/darkness on sensors and equipment)
- The machines work under vibration (influence of vibration on sensors and equipment)

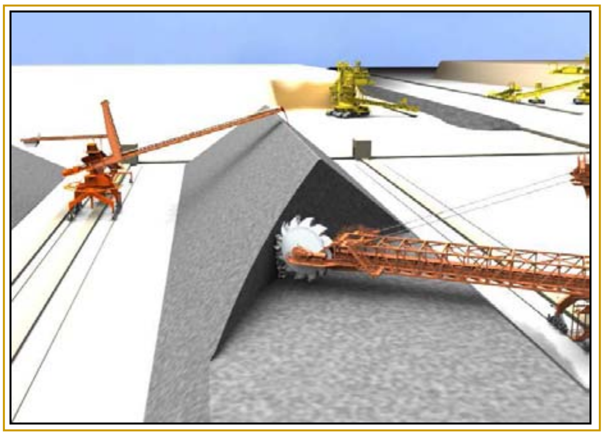


Figure 8-5: Stacker and reclaimer at stock yard.

It is important to use a powerful sensor whose signal is able to be carried across the relatively long distance between the emitter and the receiver.
Theoretically there are three main possibilities to prevent the collision between the boom and the stockpile.

1) Ultrasonic sensors
2) Microwave sensors
3) Laser sensors

8.4.2 Ultrasonic Sensors

As like as other kinds of sound waves, the ultrasound (Figure 8-6) can be affected by wind and storm. Apart from that, the ultrasound systems rarely have a guaranty for ranges over 15 meters because of the low energy of the waves used.
Of course easy setting and adjusting, low price, insensitive to contamination (because of self-vibrations) are some important advantages of the ultrasonic sensors.
Ultrasonic sensors can be mounted inclined to the boom facing to the stockpile. With this idea the distance of the boom and the stockpile will be measured simultaneous. With decreasing the distance (minimal distance set by the device) an alarm raises and the machine stops.

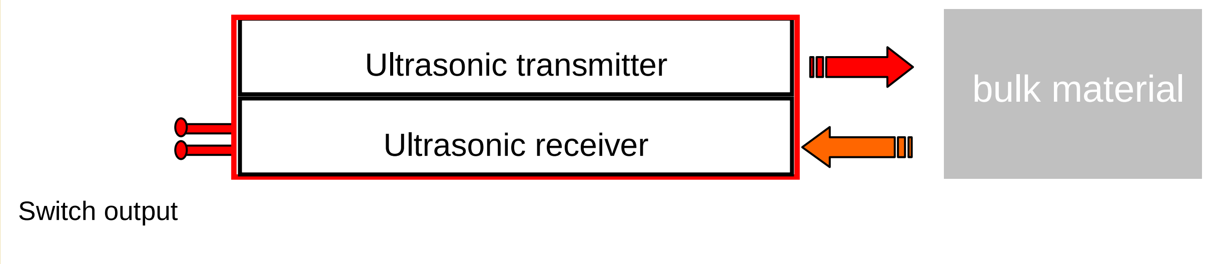


Figure 8-6: Ultrasonic sensor.

8.4.3 Microwave (radar)

Here the frequencies from 10 to 50 GHz are in use. These sensors are used in range of maximum 25 meters and hence they are not useful for our purpose.
Generally the Ultrasonic and microwave are not suitable for this problem because of the following point:
Different bulk materials will be transported on sites. Different materials have different grain size and this means different absorption factors. At the other hand the microwave sensors are relative high priced in comparison with ultrasonic sensors.

8.4.4 Laser

Laser system is another possibility for the collision prevention. It is noteable that a vibration-free construction for the sensor assembly is not possible because of the long construction of the boom. The adjusting of the sensor parts (“sender and receiver” or “sender/receiver and reflector) on the boom must be carried out very accurately, because the laser beam spreads out like a direct line. The possibility of meeting the receiver is very low (because of the vibrations of the boom caused by its long construction) and this could be an important problem by the laser systems. Distance does not have influence on the laser systems (in this project) and it’s very easily adjustable because of the visible red light[1]. A high (and the same) accuracy over the entire boom is another important factor for the collision protection.

1) There are two ways to adjust the position of laser devices:
- With the help of the laser receiving device (making the infrared beam visible (red)) or
- Determining and positioning of the laser device in the software.

8.5 Result of Systems-Comparison

After discussing the main advantages and disadvantages of the above sensor mechanisms, and taking the 4 important working conditions:

- dusty working area
- the influence of day and night (light) on sensors
- the influence of boom vibration on sensors
- the length of the boom (large distance)

into consideration, the laser sensor has been chosen for the purpose of collision prevention between the boom and the stockpile in field of open pit mining.

In the following pages different constructions and arrangements for laser systems will be discussed and the feasibility of the ideas will be examined (consulting with different manufacturer).

Each Figure (arrangement of laser equipment) will be discussed with taking the factors, named above, in mind. For more details of physical principle and some characteristics of laser please refer to the theory part.

System with one transmitter and one receiver

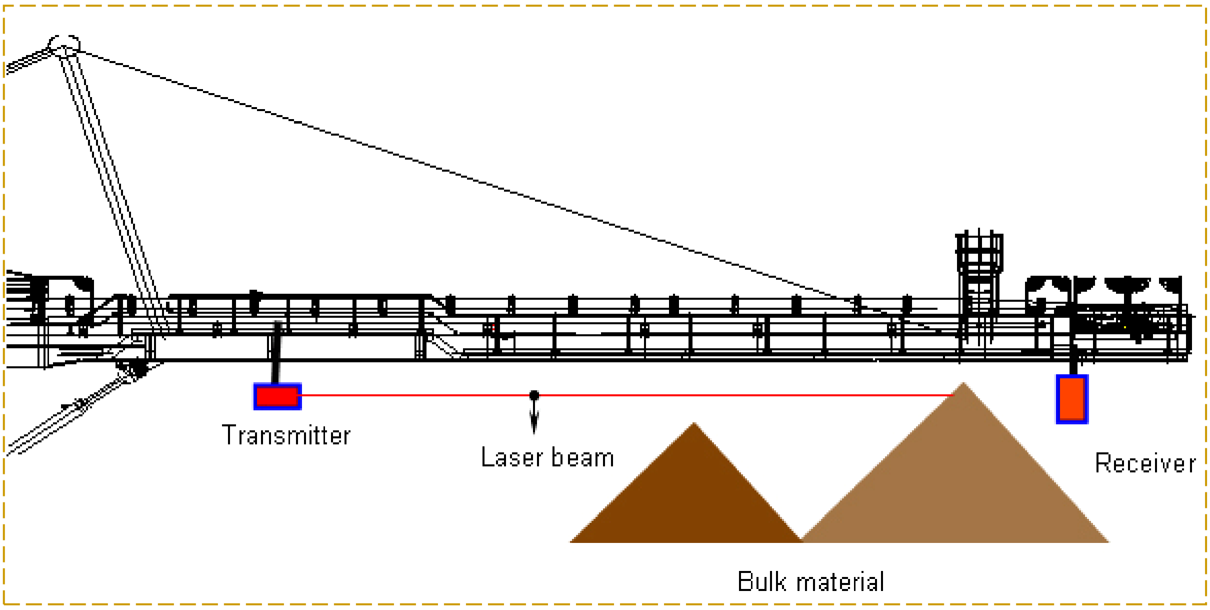


Figure 8-7: Laser system with one sender and one receiver.

Laser system with one transmitter at the back of the boom and one receiver at the front of the boom (Figure 8-7) is one of the simplest and cheapest arrangements for laser systems. This system shall be used on relative short booms; otherwise the probability of aiming the receiver is very low (because of the vibration and the sag of the boom).

Dust which arises from the stockpile is not good for the receiver which is located at the front of the boom, but the transmitter is located in a better position (with less dust particles).

Generally, high pressure air housing is recommended for open pit mining areas with a high amount of dust (with a low ambient humidity).

The sunshine is always a risk for the laser functionality. Putting the receiver on the front of the boom is recommended, because the boom has at most of the operation time a positive slope and is safe against the sun rays.

System with one transmitter/receiver and one reflector

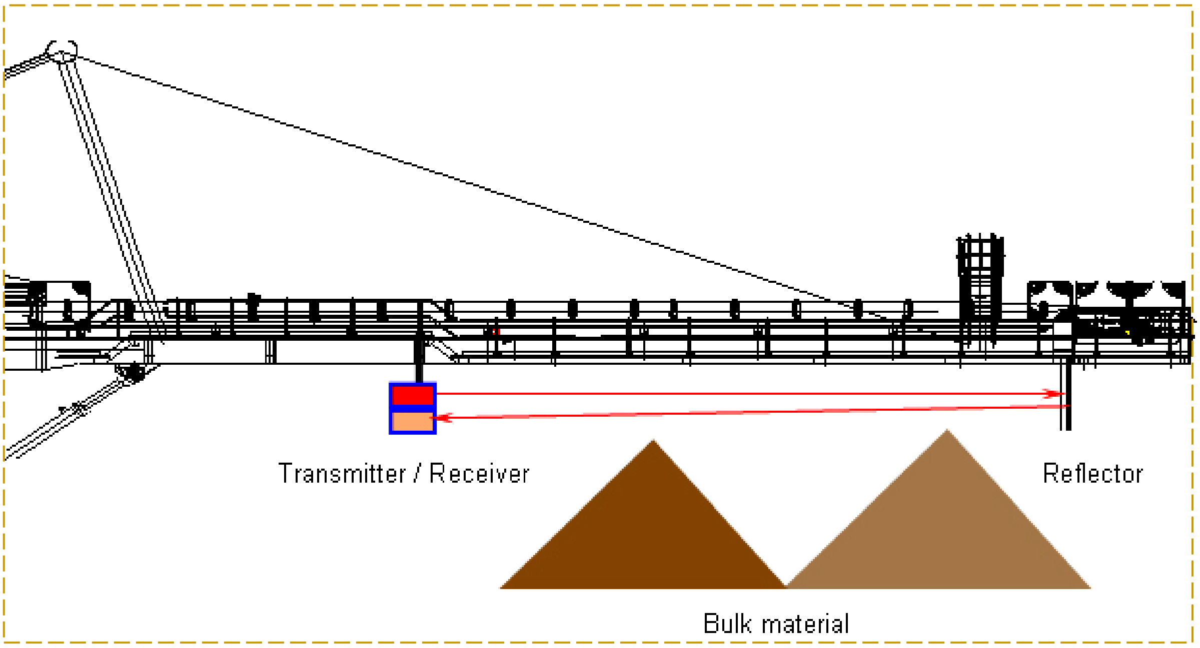


Figure 8-8: Laser system with one transmitter/receiver and one reflector.

Laser system with one transmitter/receiver in the same housing at the back of the boom and a reflector at the front of the boom, as shown in Figure 8-8 is also one of the simplest and cheapest arrangements for laser systems. This system shall be used on relative short booms; otherwise the probability of aiming the receiver is very low.

The light spot diameter is approx. 50 cm at the distance of 40 meter. It means a relative large reflector shall be used for a correct performance.

Dust which arises from the stockpile is not good for the reflector which is located at the front of the boom, but the transmitter/receiver is in a better situation.

A modulated transmitting laser beam can be a nice solution against the sunshine disturbances. The beam can be modulated either by its amplitude or by its frequency.

System with two transmitters and two receivers

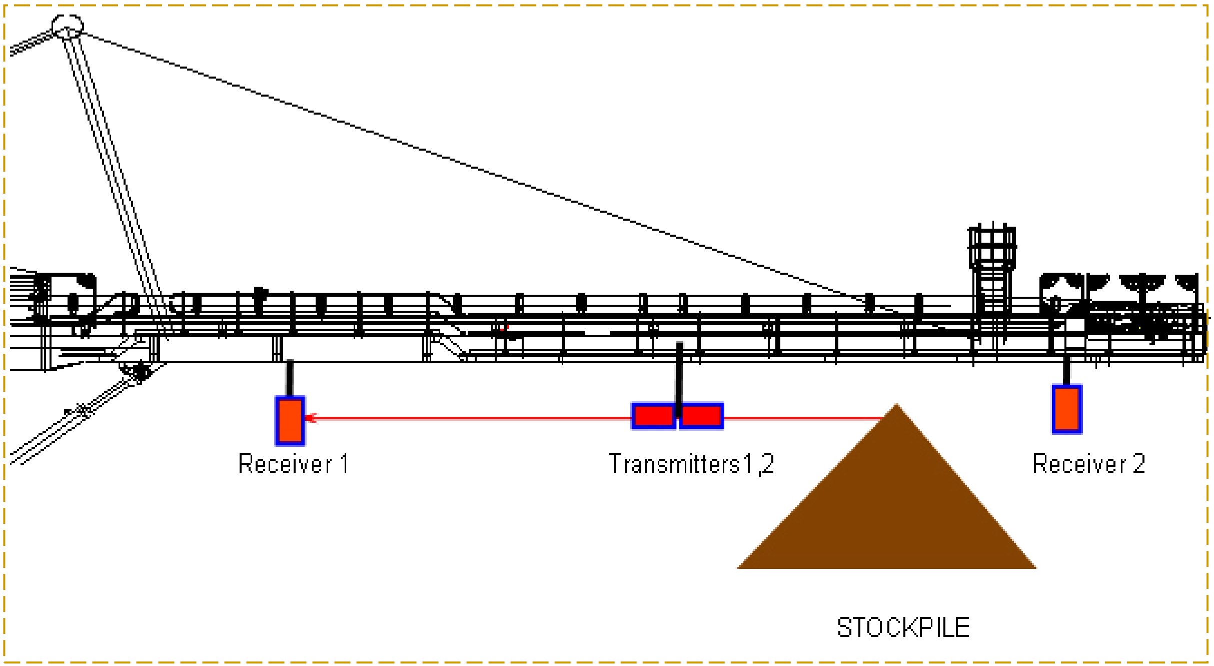


Figure 8-9: Laser system with two transmitters and two receivers.

Laser system with two transmitters in the middle of the boom and two receivers at the front and back side of the boom is another arrangement for laser systems (Figure 8-9). This system is more expensive in comparison with the first two arrangements but it can be strongly recommended for long booms.

Existing dust is not good for the receiver 2 which is located at the front of the boom and also for the transmitters, but the receiver 1 is located in a better position (with less dust particles).

Of course collision between the transmitters and the stockpile is another problem for this type of arrangement when the stockpile stands directly under the transmitters.

System with one transmitter, one receiver and one lens

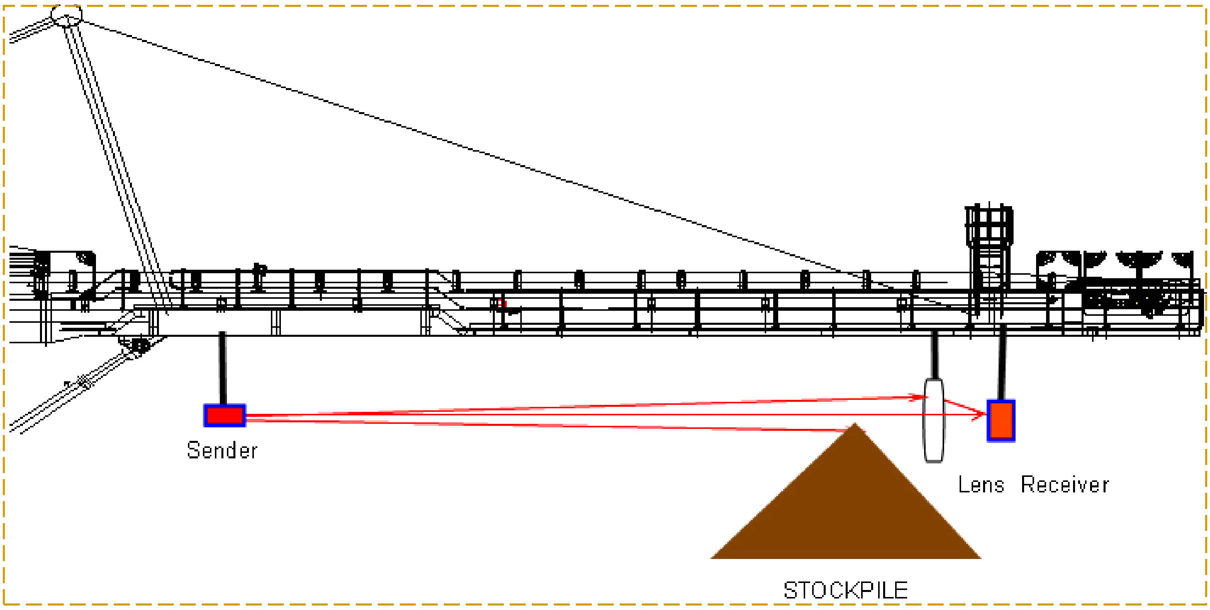


Figure 8-10: Laser system with one transmitter, one receiver and a lens.

Laser system with one transmitter at the back of the boom and one receiver with a lens at the front of the boom is another arrangement for laser systems as shown in Figure 8-10. This system can be easily used on relative long booms. The receiver is located at the focal point of the lens so that all deviated beams come to the receiver.

Existing dust can be problematic for the receiver and the lens which are located at the front of the boom but the transmitter is located in a better situation. Generally this system shall be used in areas with a high humidity or on machines equipped with dust suppression system.

System with two transmitters, two receivers and two lenses

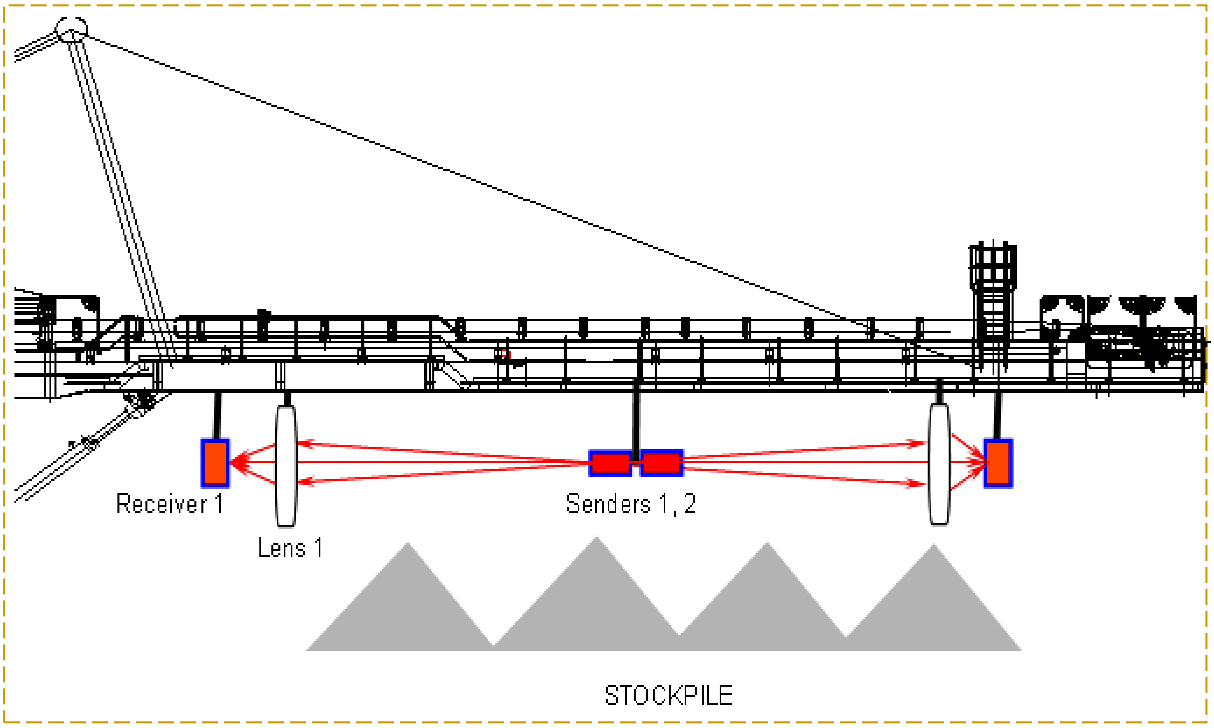


Figure 8-11: Laser system with two transmitters, two receivers and two lenses.

The functionality of this arrangement (Figure 8-11) is like the system explained before. The only difference is that the system has two transmitters in the middle of the boom and two receivers with lens at the front and back of the boom. This system can be easily used on long booms.

Existing dust can be mainly problematic for the receiver 2, the lens and also the two receivers which are located at the front of the boom but this system shall be generally used in areas with a high humidity or on machines equipped with dust suppression system. This system as like as the system which will be explained in type 7 are the most expensive ones with high expenditure.

System with one transmitter, two receivers and one mirror

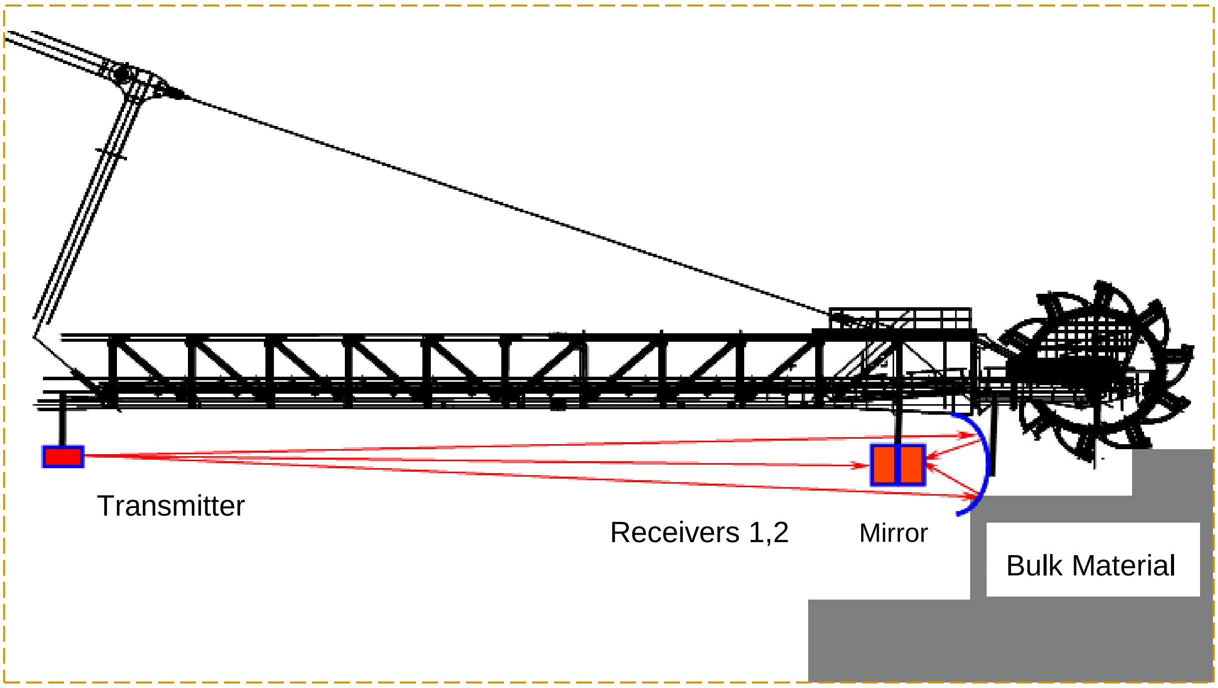


Figure 8-12: Laser system with one transmitter, two receivers and one mirror.

The functionality of this arrangement (Figure 8-12) is like the system explained in type four. The only difference is that this system has two receivers with a concave mirror at the front. The receiver 1 which is located face to face to the transmitter is for normal conditions and the other one which is facing to the mirror is responsible for the deviated beams which occur under vibration. This system can be easily used on relative long booms and shall be used in areas with a high humidity or on machines equipped with dust suppression system. Existing dust can be mainly problematic for the receiver 2, the lens and also the two receivers which are located at the front of the boom.

System with two senders, two mirrors and four receivers

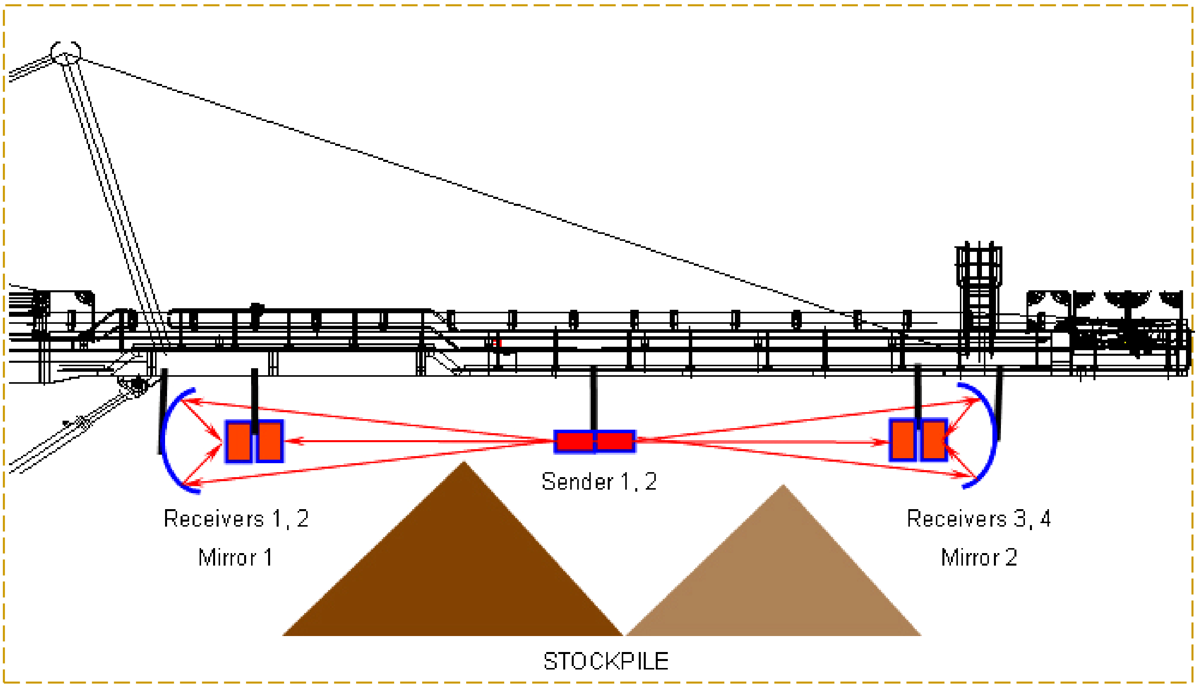


Figure 8-13: Laser system with two senders, two mirrors and four receivers.

This arrangement is like the system explained above. The only difference is that this system is equipped with two transmitters in the middle of the boom and two concave mirrors at the front and back of the boom (Figure 8-13). The receivers 1, 3 which are located face to face to the transmitters are for normal conditions and the other ones which are facing to the mirrors are responsible for the deviated beams which occur under vibrations. This system can be easily used on long booms and shall be used in areas with a high humidity or on machines equipped with dust suppression system. Existing dust can be mainly problematic for the mirror and also the two receivers which are located at the front of the boom and for the transmitters.

8.6 LMS System

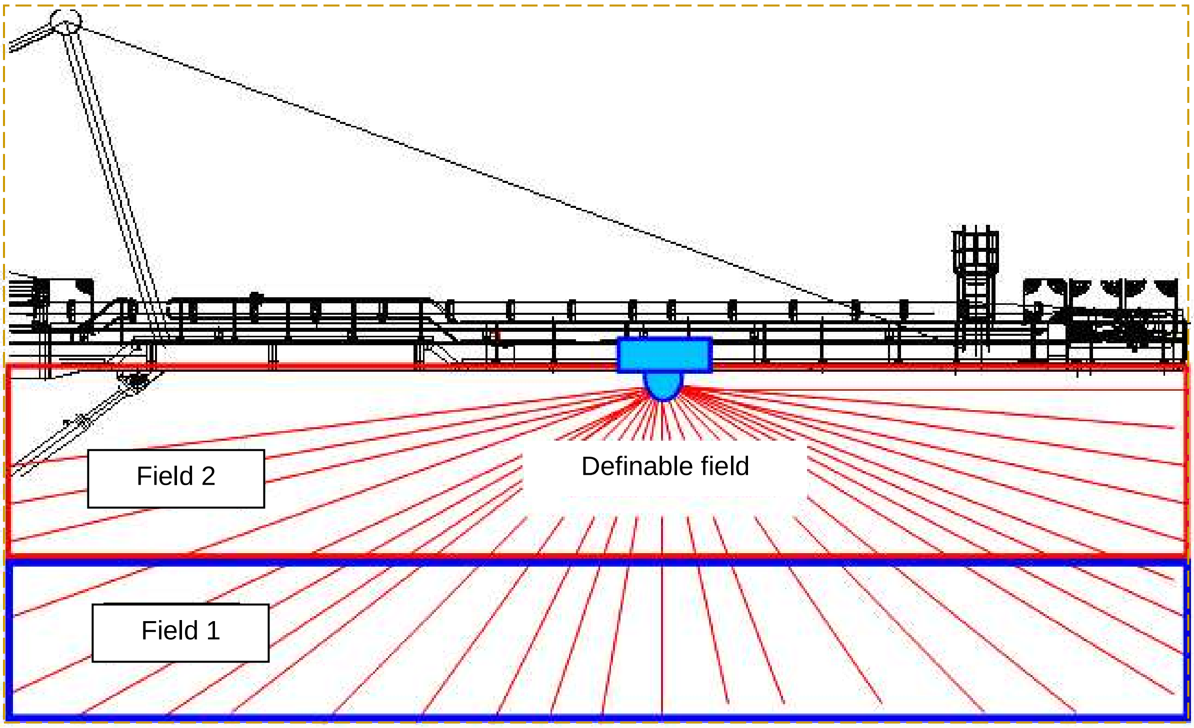


Figure 8-14: LMS field definition.

LMS (Laser Measurement System) is another possibility for collision protection purposes. The LMS has some important advantages in comparison with the prior systems and arrangements, for example, the sunshine is not a problem, since it faces downwards. Since the LMS is sitting in the middle of the boom, the problem of vibration of the boom (because of the length of the boom) and the sag of the boom (because of the weight of the transporting material) is also solved. Applying a dust shield in front of the lens and facing it downwards prevent dust deposits on the lens. In the cases with a high amount of dust in the air (open pit mining areas with a low humidity), the sensor can be installed in a high pressure air housing for keeping the surrounding dust away.

A significant characteristic of LMS is that the operator can define two or three different fields, shown in Figure 8-14. The first field for example, defines a higher distance to the stockpile (field 1) and the second field with a shorter distance (field 2). In other words disturbing the first field could raise an alarm or stepping the speed of the boom down and finally stopping the machine when the second field is disturbed. In the next pages some arrangements will be discussed to find an optimal positioning for the sensors. The Figure 8-15 gives a better understanding of the positioning of the sensors on the boom.

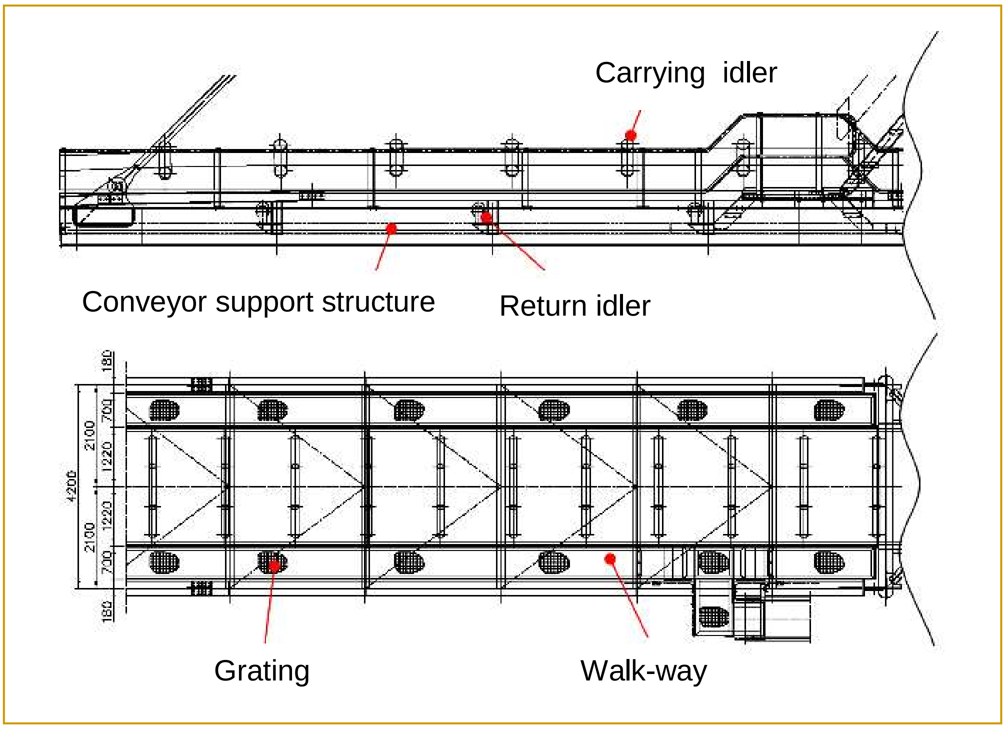


Figure 8-15: Side and top view of the conveyor boom.

LMS positioning 1

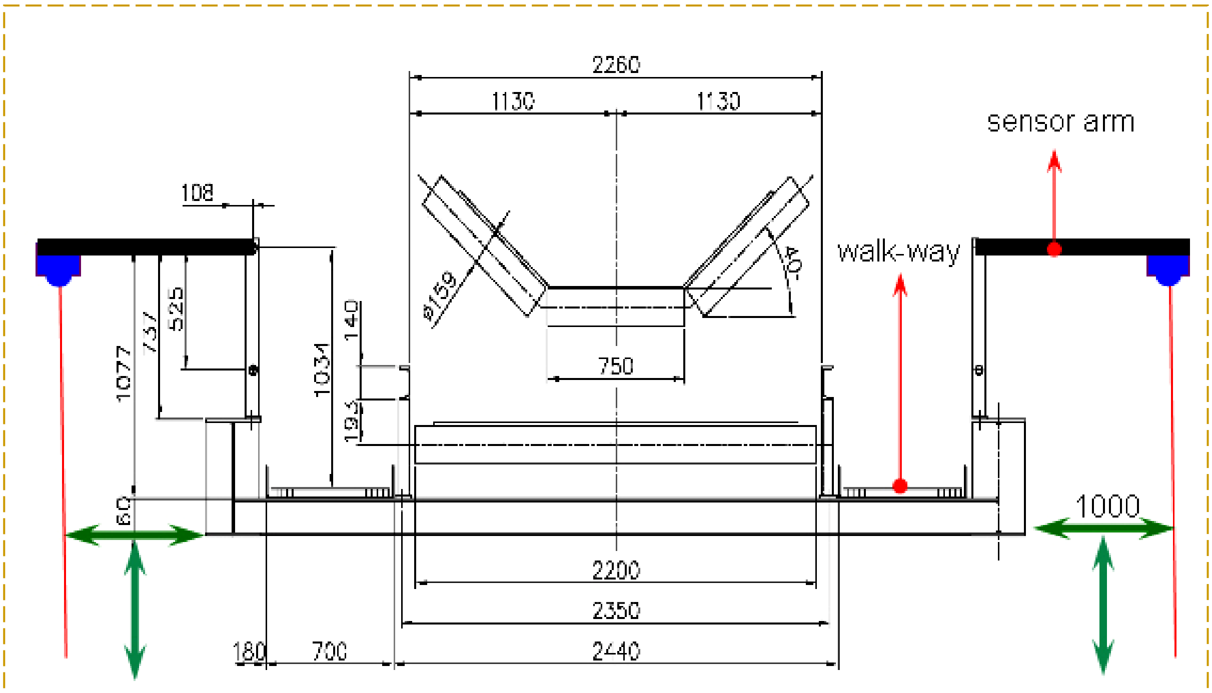


Figure 8-16: LMS positioning with arm.

Safety pads (green arrows) between the boom and the stockpile (Figure 8-16) after stopping the machine should be considered in order to avoid the collisions because of the inertia of the boom. The boom has a slewing velocity of about 40 m/min, as large as its travel speed, and the machine needs about 300 to 500 mm to be completely out of motion. That means with a 1000X1000 (mm) distance of the sensor (beam) to the boom, a safety distance between the boom and the stockpile after stopping the machine is assured.

LMS positioning 2

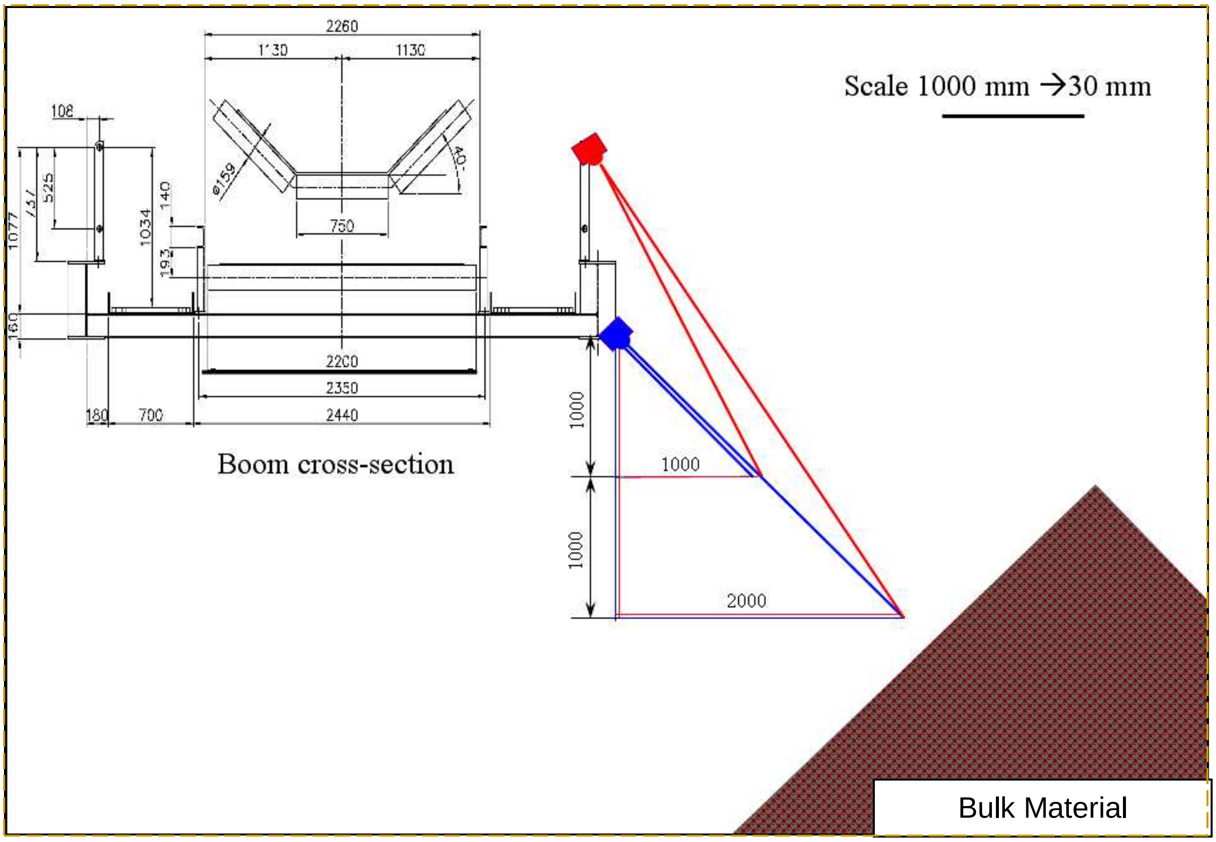


Figure 8-17: LMS positioning arm-less with angle.

The second variation of LMS arrangement is to position the sensors directly on the boom structure, as shown in Figure 8-17. In this case the definition of the field can be fulfilled by defining the length of the beam as like as the angle of the sensor. The advantage of this arrangement is that the sensors are mounted at the construction which simplifies the maintenance and cleaning tasks. On the other hand the sensors are safer against the collision in comparison with the last arrangement.

LMS positioning 3

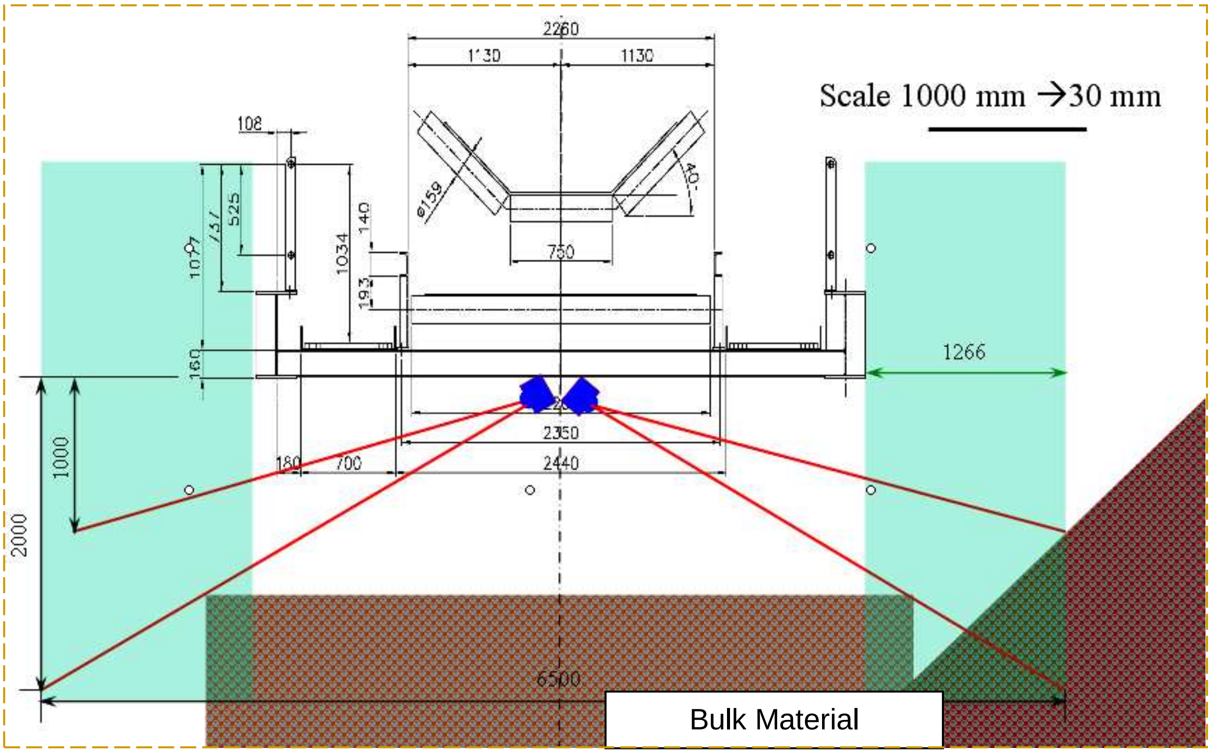


Figure 8-18: Under the boom back to back.

In this arrangement, the sensors are mounted back to back under the boom directly at the construction (Figure 8-18). The advantage of this system is the simplified cabling of the sensors. The area under the conveyor is also safe in this arrangement. The field can be defined as like as prior arrangements with defining the length of the beam as well as the angles of the sensors. Another great advantage of this type of assembly is that only one high pressure air housing is enough for both of the sensors.

LMS positioning 4

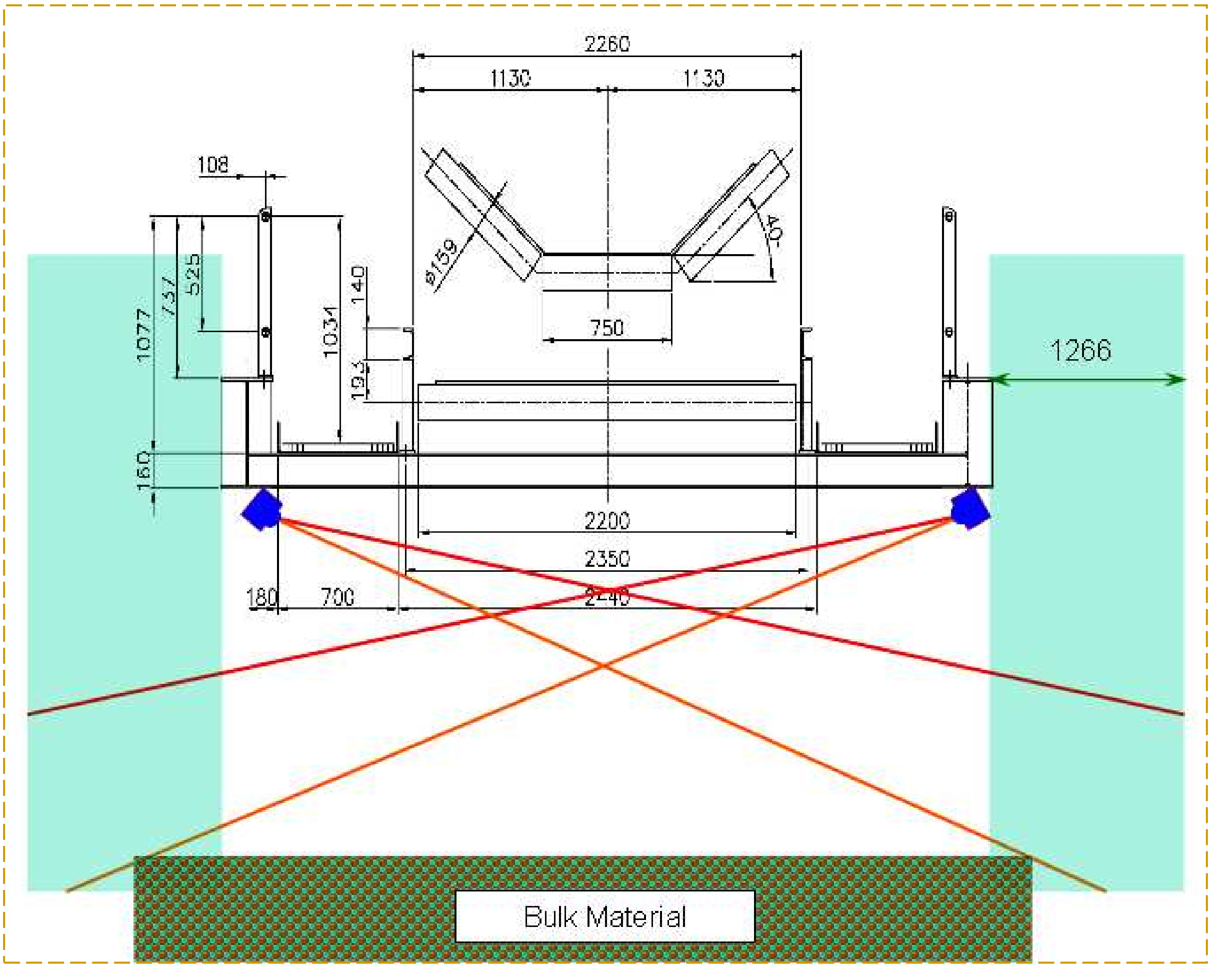


Figure 8-19: LMS positioning face to face.

In this type of arrangement the sensors are mounted also directly at the construction (Figure 8-19). Here the only advantage is that the area under the conveyor boom is better covered and is more safely. The collision between the radiations can be prohibited by transmitting them in different phases in other words with synchronizing the sensors.

8.7 LMS Functionality

After a feasibility study on different arrangements, discussing the advantages and disadvantages of different systems and taking the costs and expenditure of different systems into account, the best solution for the purpose of collision prevention system with laser is as follow:

8.7.1 Laser Type

The Laser Measurement System (LMS), as shown in Figure 8-20, used for the purpose of collision protection between the conveyor boom and the stockpile has a scanning angle of 180° which is used in the industry for object measurement and determining its position as well as Area monitoring and detection applications. The device works in the areas with maximum relative humidity of 90% and in operating temperatures up to 50 ℃. A Dust prevention shield, a sun guard, a replaceable drying agent cartridge and purging air housing make the operation of the device under rough weather conditions safe and accurate.

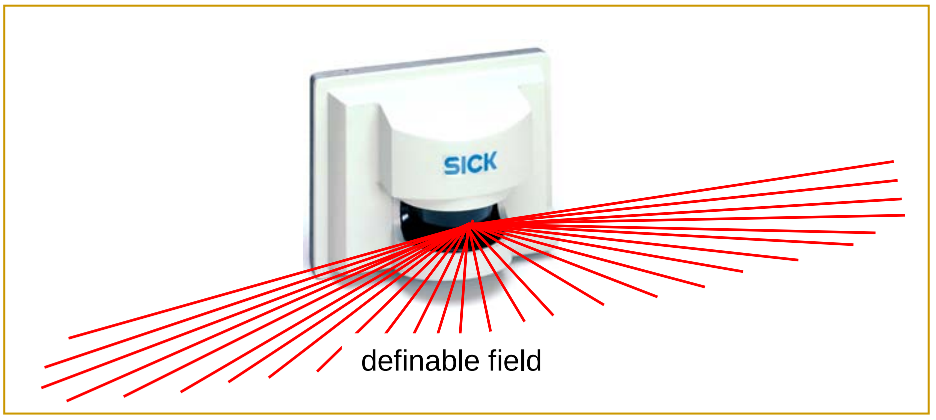


Figure 8-20: Laser Measurement System (LMS).

The non-contact measurement system which is used in this work scans its surroundings two-dimensionally with a radial field of vision using infra-red laser beams (λ = 905 nm). A great advantage of this system is that it requires neither reflectors nor position marks. Additionally this system has some other brilliant advantages which made it possible to take it in operation such as:

- Rapid scanning times, thus measurement objects can be move at high speed.
- Backgrounds and surroundings do not have any influence on the measurements.
- Measurement objects may be in any position.

- Automatic fog correction.
- Pixel-oriented evaluation for cutting raindrops and snow flakes out.
- Measurement data is available in real-time and can be used for further processing or control tasks.
- Active system - no illumination of the measurement area required.
- Completely waterproof (IP 67).
- Thermostat controlled heater for temperature ranges below 0 ℃.

8.7.2 LMS-Components

A standard LMS consists of the following components:

- laser scanner
- evaluation electronics
- evaluation software
- data interface
- digital switching input and outputs
- function indicators (LED)

8.7.3 Principle of Operation

The LMS operates by measuring the time of flight of laser light pulses. The reflected beam from the object will be registered by the receiver. The time between the transmission and reception of the impulse is directly proportional to the distance between the device and the object. An internal rotating mirror (motor speed 75 Hz) deflects the pulsed laser beam so that a curtain-shaped scan is made of the surrounding area. The counter of the objects is therefore determined from the sequence of the impulses received.

8.7.4 Diagrams and Numbers

In the following pages some important diagrams and facts from the manufacturer company SICK will be discussed and analyzed.

8.7.4.1 Range and spot diameter

In a radial field of vision, a light impulse (spot) is emitted every 0.25°, 0.5°, or 1° depending on the device setting. As a result of the beam geometry and its diameter the spots overlap up to a certain distance. The following diagram shows spot spacing in relation to the range and the corresponding spot diameter.

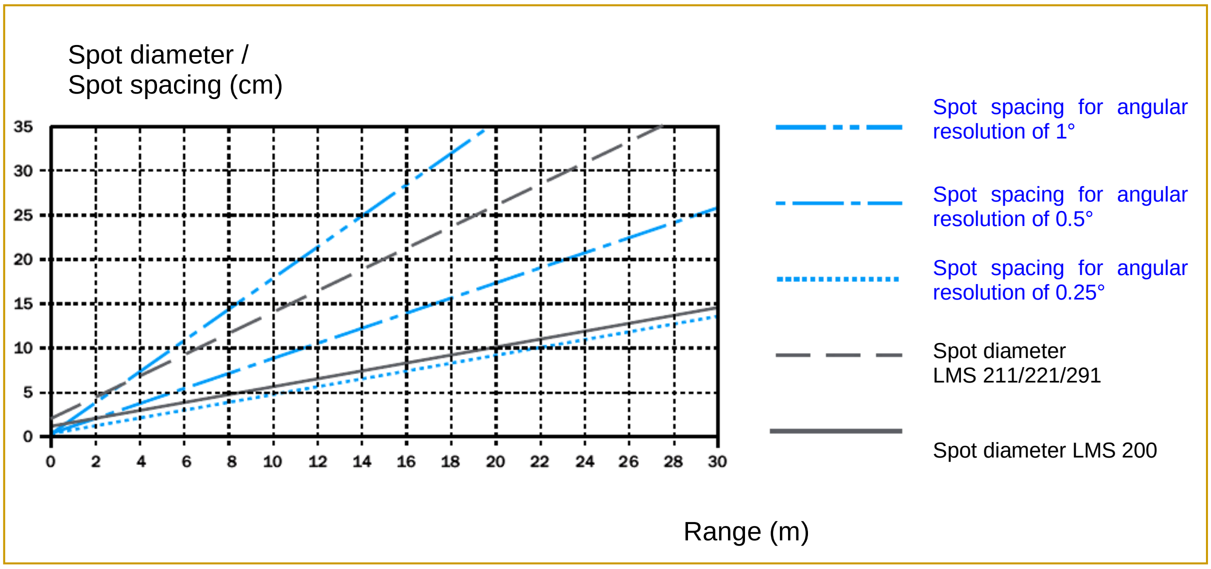


Diagram 8-1: Spot spacing diagram of laser beam.

With the help of the configuration system, it is possible to define different angular resolutions (1°, 0.5°, and 0.25°). A device with an angular resol ution of 1° responds more rapidly than the others and is perfectly sufficient for this project.

8.7.4.2 Reflectivity of various objects

The operating range of the LMS depends on the reflectivity of the objects (bulk material) and the transmission strength of the device. The following diagram shows the reflectivity of the spot in relation to the distance between the device and the stockpile.

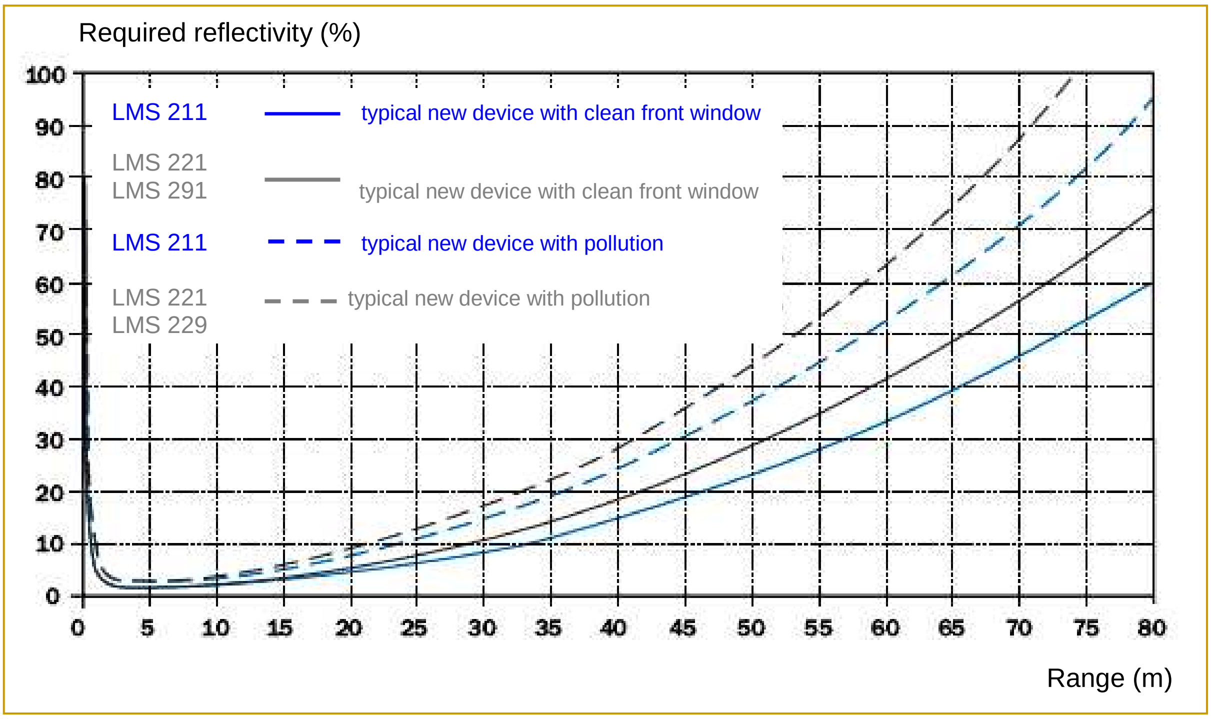


Diagram 8-2: Relationship between reflectivity and range with good visibility.

8.7.4.3 Reflectivity in fog (≈ dust)

The so called blind area (red) has a damping function for the device in foggy (dusty) situations, so that the dust or fog directly on the device can be neglected. The red area, as shown in Diagram 8-3, is approximately one and half meter wide and thus the safety distance between the conveyor boom and the stockpile should be at least 2 meters. The device registers an error when the reflected beam does not received within two completely revolutions of the mirror. This can be set by configuring the device with the software. Also another way to neglect the dust cloud or fog is to set the error message within 10 or more revolutions of the mirror. In this way the receiver receives no reflection for a longer time1 and thus registers no error.

1) There are 180 measured values with angular resolution of 1° and maximum scanning angle of 180°. The time to fulfill a completely revolution of the mirror is about 13 ms and approximately 130 ms for ten revolutions.

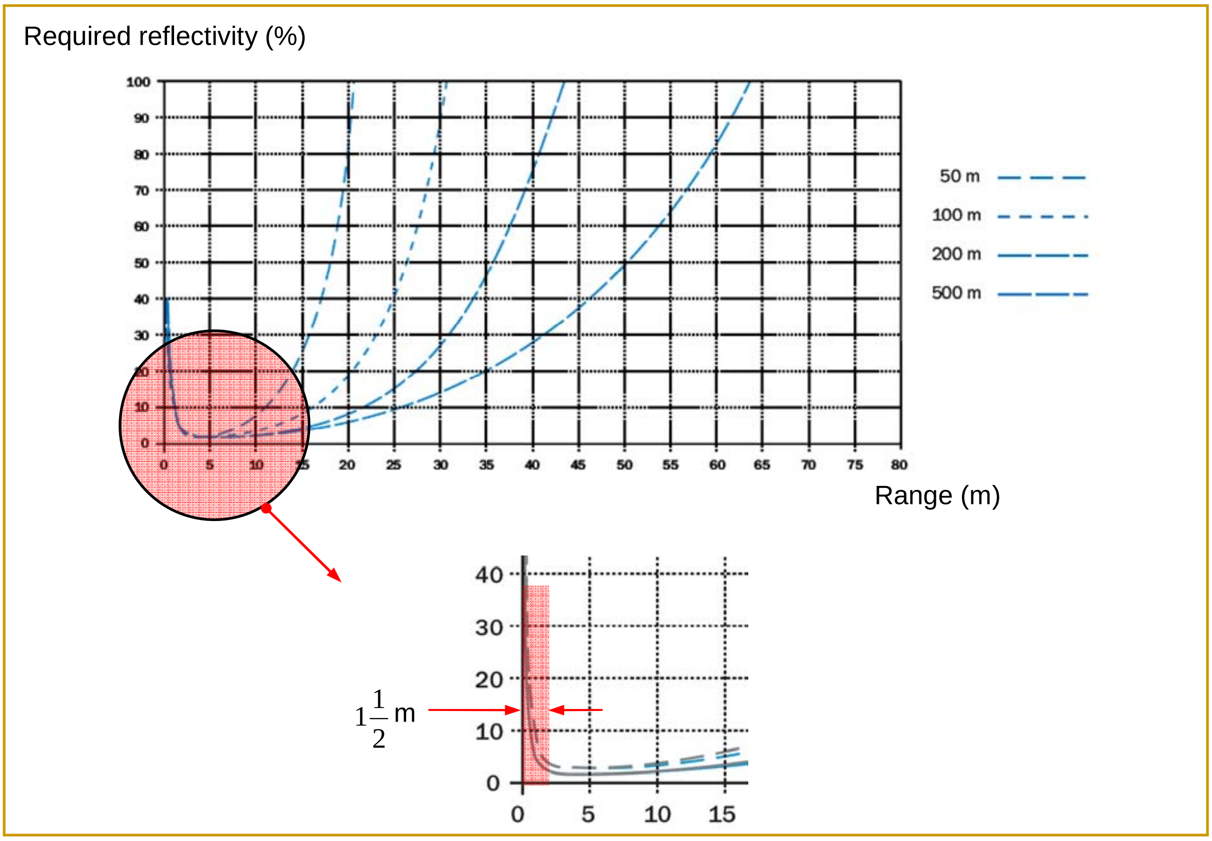


Diagram 8-3: Relationship between reflectivity and range in fog.

8.7.5 Drying agent cartridge

The laser device is equipped with a replaceable drying cartridge, as shown in Figure 8-21, so that in operating situations with extreme humidity, the replacement of the cartridge after 5 to 6 month makes it capable for further operation period. Normally the replacement of the cartridge takes place every 4 to 5 years.

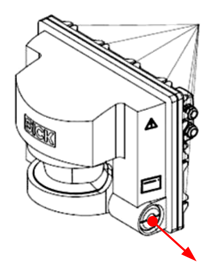


Figure 8-21: Drying agent cartridge.

8.7.6 Weather protection hood

The laser device has an operating temperature of -30 to +50 ℃. In cases of using the device under rough weather conditions, a weather protection hood shall be mounted to protect the device from direct sunshine as shown in Figure 8-22.

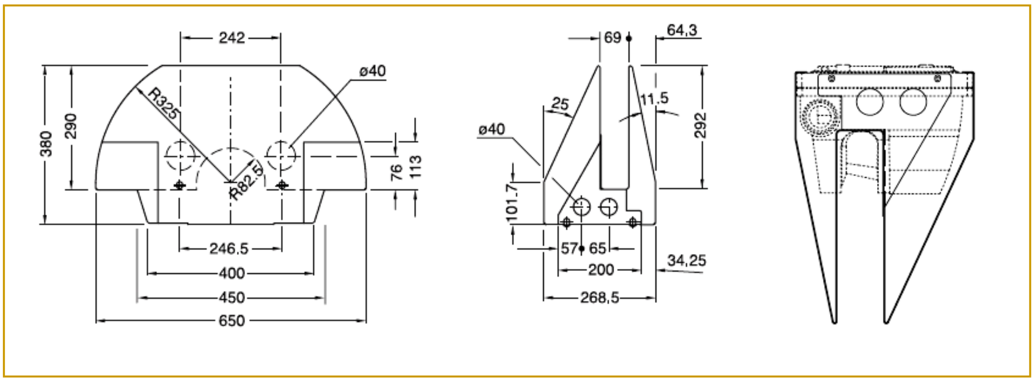


Figure 8-22: Weather protection hood.

8.7.7 Synchronisation of two laser sensors

The Laser sensors are capable of synchronization with the help of a soft ware and a hard ware (connection box, mains adapter) as shown in Figure 8-23. It is noteable that both of the sensors must be supplied from a common power supply unit (The separation of the power supply must first take place in the connection box), and it shall be considered that the cables should not exceed 5 m.

The sensors must be synchronized in order to prevent the collision disturbances between the emitted pulses of the beams in case of facing the sensors to each other or when the beams cut each other (for example LMS arrangement No. 4).

Synchronisation of the beams means that the pulsed spots will be emitted from the master and slave sensor in different phases. In other words when the master emits a pulsed beam, the slave sensor receives the reflected beams from the object and vice versa.

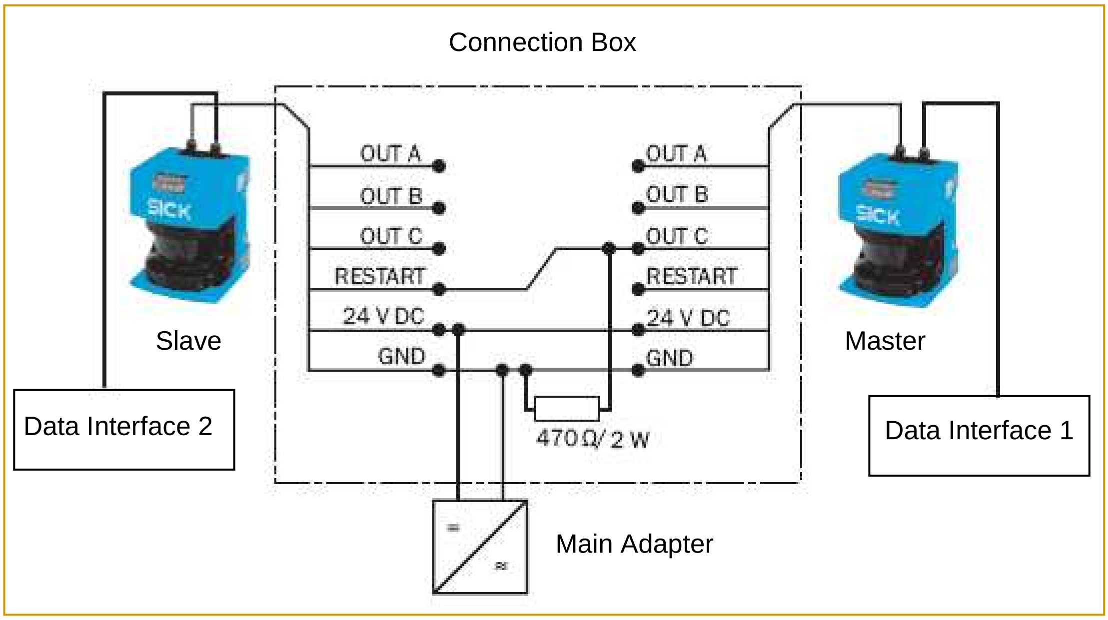


Figure 8-23: Master-slave connection circuit.

8.8 LMS Tests

In this chapter, different types of tests and experiments will be analyzed, which through them withstand of the device against rough climate conditions and its ability for showing high performance in different conditions has been proved.

The LMS (sensor) is installed on a vibrating screen for making the simulation closely to the real situations (vibrating boom). The sensor runs with a 24 V DC / 1.8 A power supply. The LMS configuration is as shown in Figure 8.24.

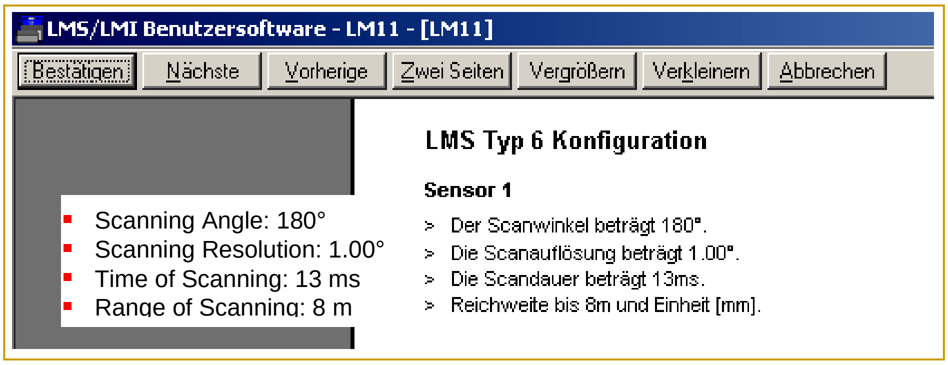


Figure 8-24: LMS configuration.

The next Figure shows the propagation of infrared beams in the hall, which make a two dimensional scanning possible. The coal dome, door and the ceiling of the hall are the uneven surfaces in the hall which are shown in Figure 8.25. Of course there is the possibility to define the coordination of the objects which are placed in the scanning area in order to neglect them for the purpose of reducing the errors by scanning. For example, with setting the diameter of objects with 50 cm makes it possible to neglect a bird which flies in the defined field and so it doesn't influence the scanning process.

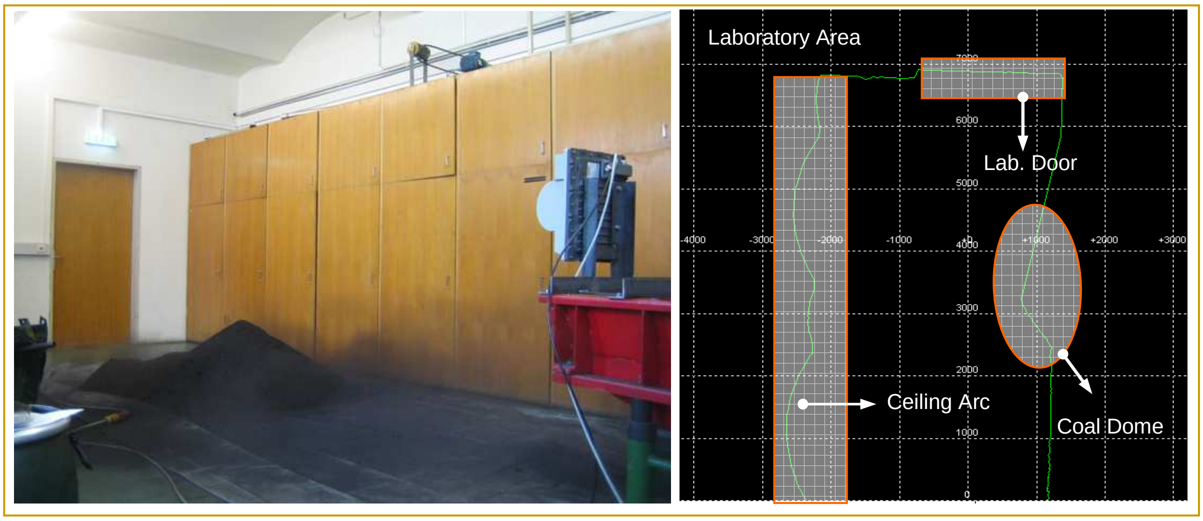


Figure 8-25: Workshop with scanning patterns.

8.8.1 Electrical circuit diagram

The LMS power will be supplied by a DCP (direct current power supply), shown in Figure 8.26. Special software is used to analyse and evaluate the changes of the beam. These changes can be caused by vibrating of the device or the presence of dust or other objects before the lens. Three indicating lamps present the condition of the defined fields (1st, 2nd and 3rd fields).

Defining two different fields (with the use of the software), for example, can make it possible to break the boom down with disturbing the outer field and stops the boom with disturbing the inner field (Figure 8.27).

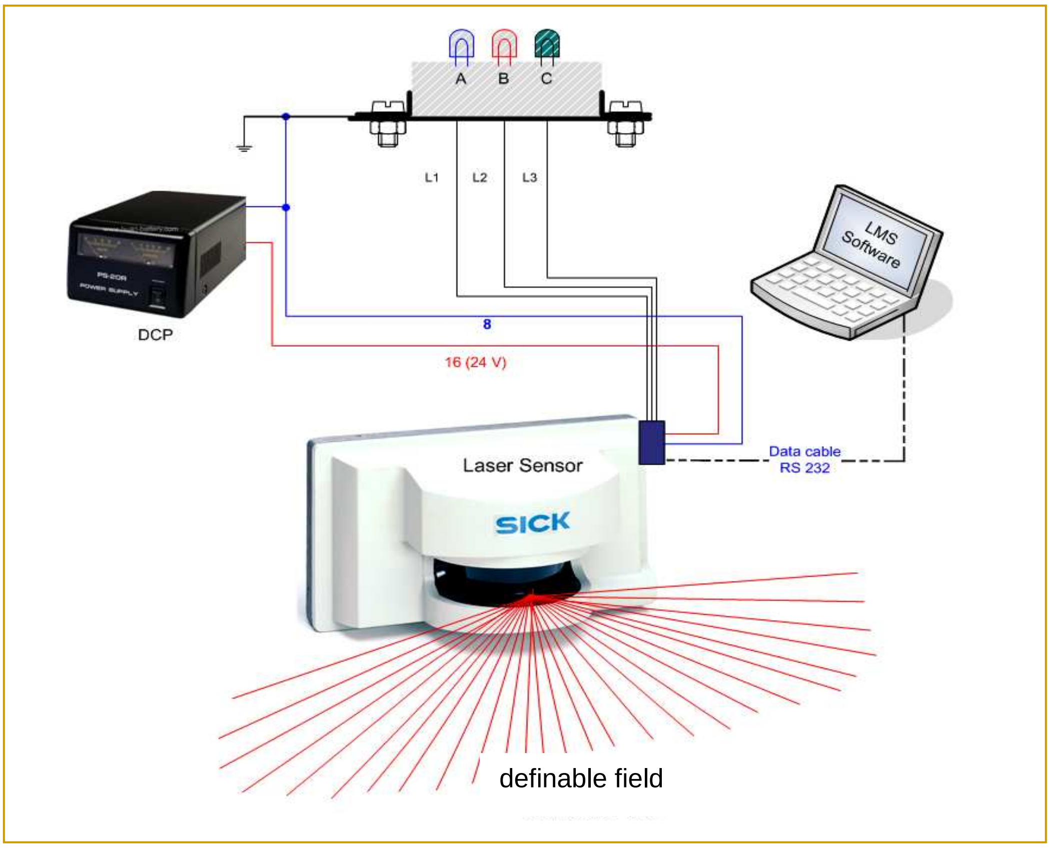


Figure 8-26: Electrical circuit of laser sensor in connection with software (schematic).

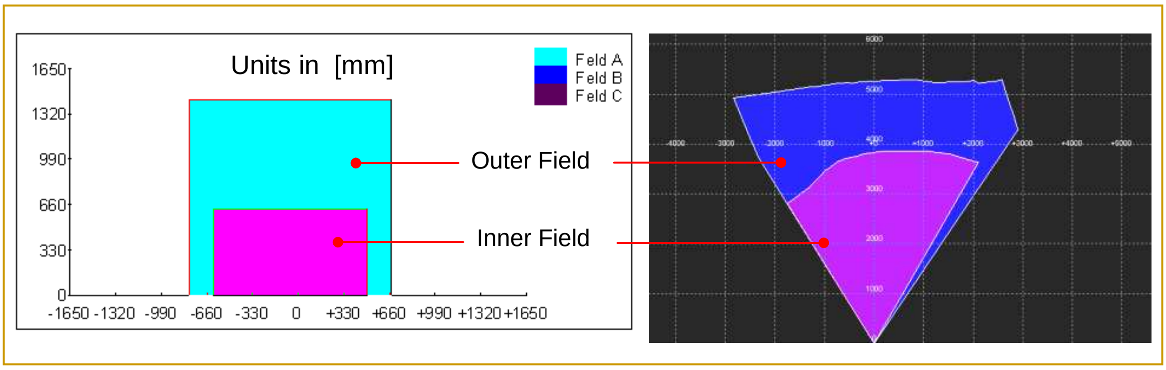
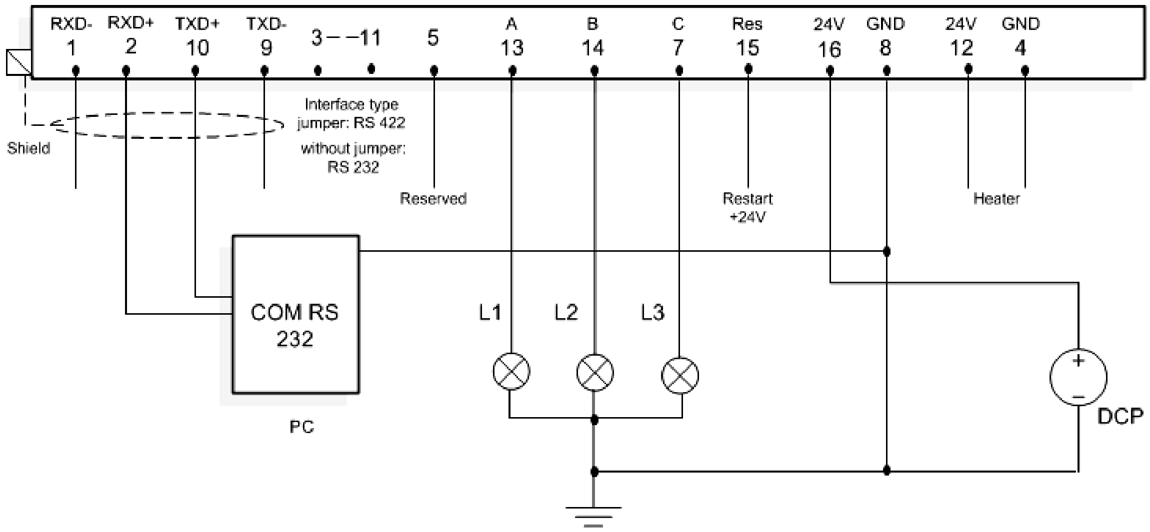


Figure 8-27: LMS field definition.

The electrical circuit of the LMS, its connection with indicating lamps and the computer is shown in Figure 8.28.



DCP: Direct current power supply 24 V DC /
L1, L2, L3: Indicator Lamps (blue, red, green)

Figure 8-28: Electrical circuit of laser sensor in connection with software.

8.8.2 Coal-stockpile test

In this test, the reaction of the laser sensor to the changes in the defined field (passing an object through the field) has been proved. The simulation has taken place with a ~ 600 mm high stock pile with the following attributes:

- Bulk material: Canadian coal (west store coal terminals)
- Angle of repose: 108°
- Grain size: Table 8.2

> 20 mm	2.63 %
10 - 20 mm	7.41 %
7.5 - 10 mm	4.20 %
0 - 3,15mm	70.13 %

Table 8-2: Bulk materials grain size.

The first test on the LMS has been done in the stationary mode of the vibrating screen. The dimensions of the sample dome and the position of LMS are shown in Figure 8.29.

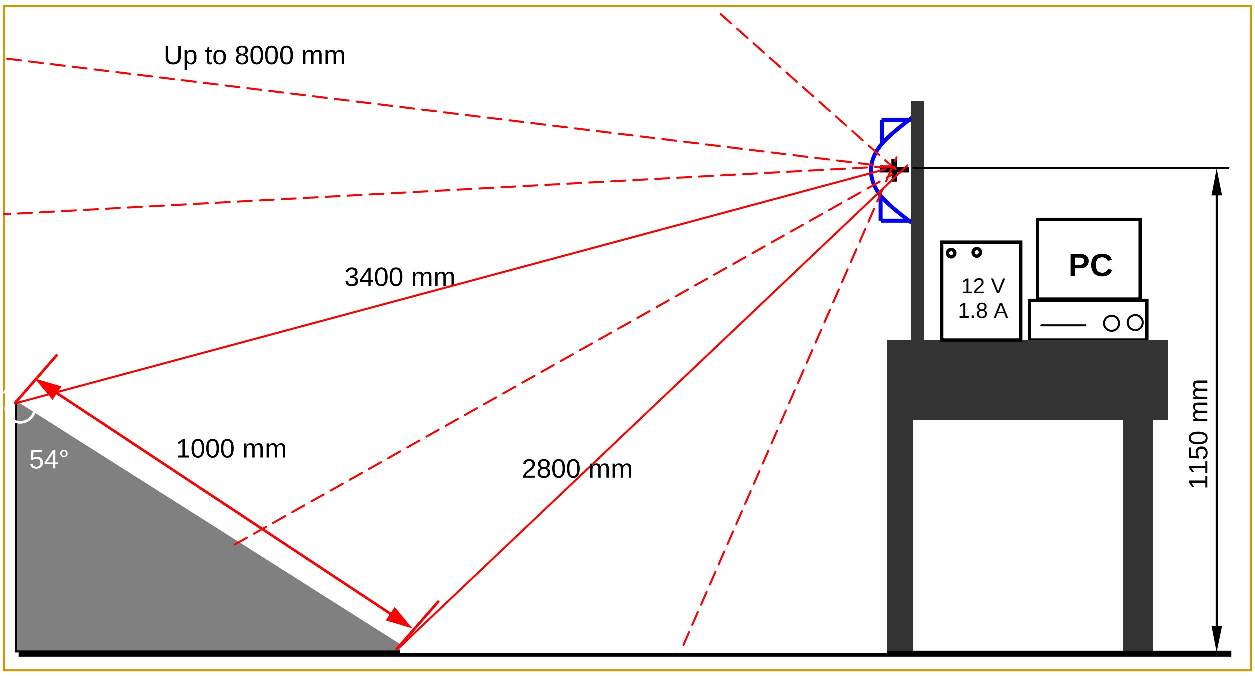


Figure 8-29: Sample coal dome test.

The area of scanning is shown in Figure 8.30. In this type of scanning pattern, the lens slit is located vertical to the dome.

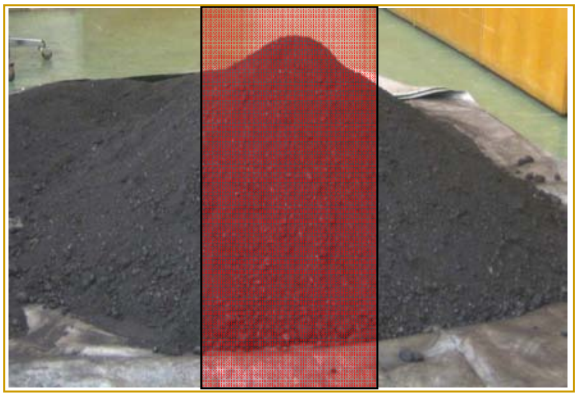


Figure 8-30: Stockpile gescannt area.

8.8.3 Vibrating Tests

A further test on the Laser Measuring System is the vibrating test. For that purpose the LMS has been vibrated with different vibrating width levels by the means of a vibrating screen. Two other stationary observations have been also considered for making the analyses more clear. The first test has been done before starting and the second one after finishing the four vibrating modes.

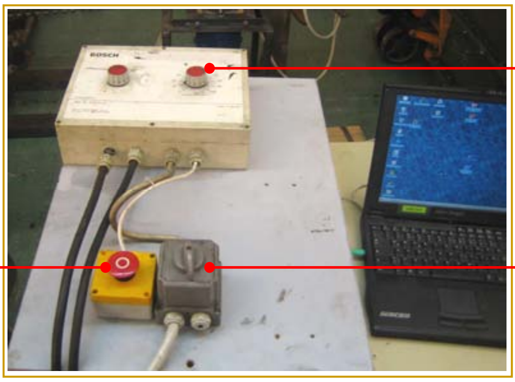


Figure 8-31: Vibrating screen control panel.

0, 5, 10 and 15 are vibration width levels in this work, which can be selected via the knob on the control panel.

The vibration measuring process has been done in the period of 3 seconds for each vibration width level (0, 5, 10, and 15) as shown in Figures (8.32, 8.33, 8.34 and 8.35).

In each Figure, the vibration amplitudes are shown in three dimensions (X, Z, and Y).

The maximum values of the amplitudes (m/s^2) are illustrated on the right side of the windows.

Direction of oscillation / Scale [m/s^2]	0	5	10	15
Max. X	27.1	21	35.9	10.4
Max. Z	14.2	19.2	25.5	5.98
Max. Y	1.77	5.26	18.4	6.26

Table 8-3: Maximum values for different vibration width levels.

a) The LMS runs with no vibration.

b) The LMS runs with vibration width level 0.

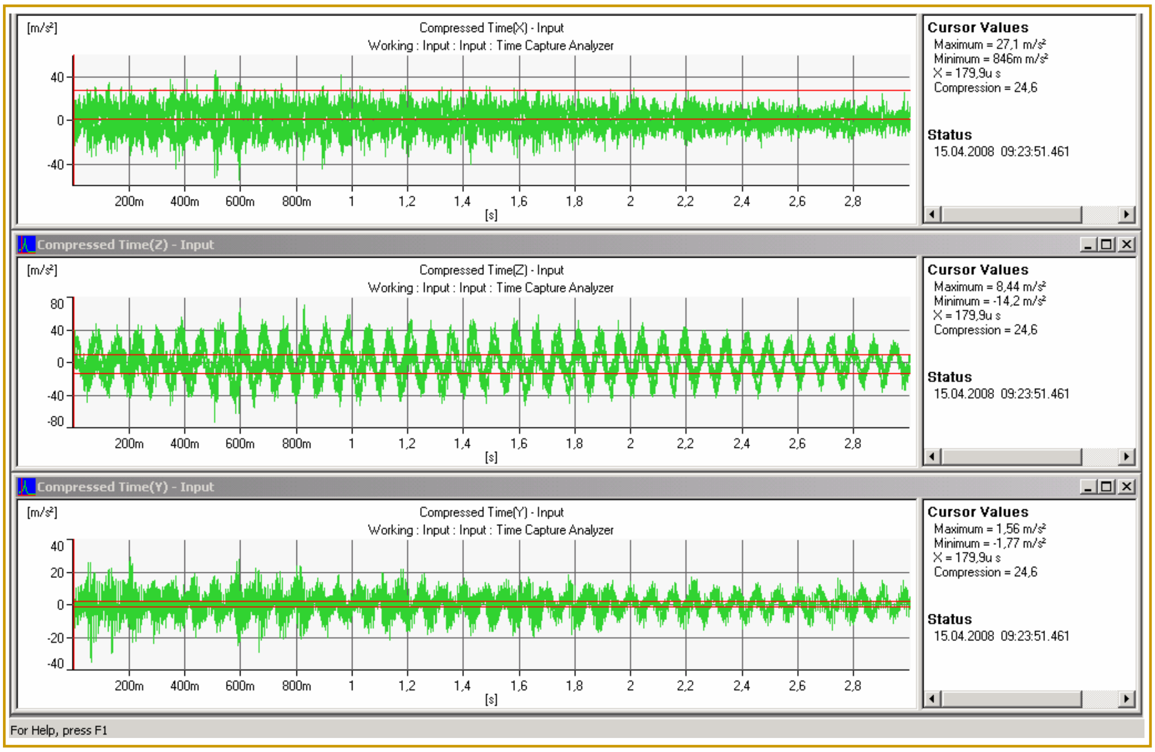


Figure 8-32: Oscillation diagrams with vibration width level 0.

c) The LMS runs with vibration width level 5.

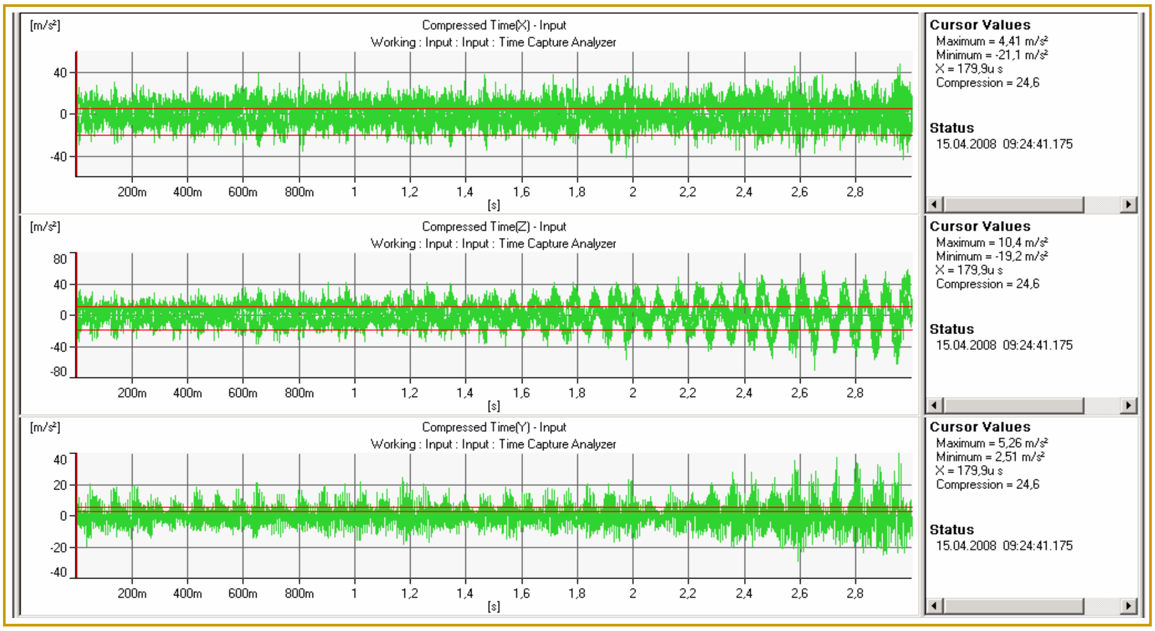


Figure 8-33: Oscillation diagrams with vibration width level 5.

d) The LMS runs with vibration width level 10.

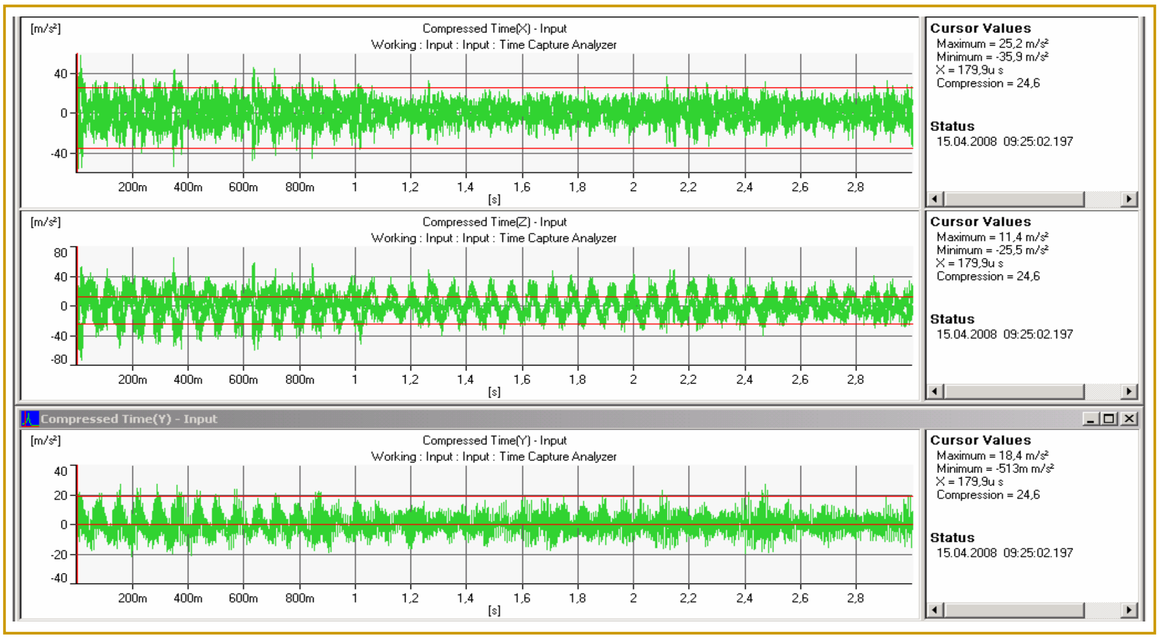


Figure 8-34: Oscillation diagrams with vibration width level 10.

e) The LMS runs with vibration width level 15.

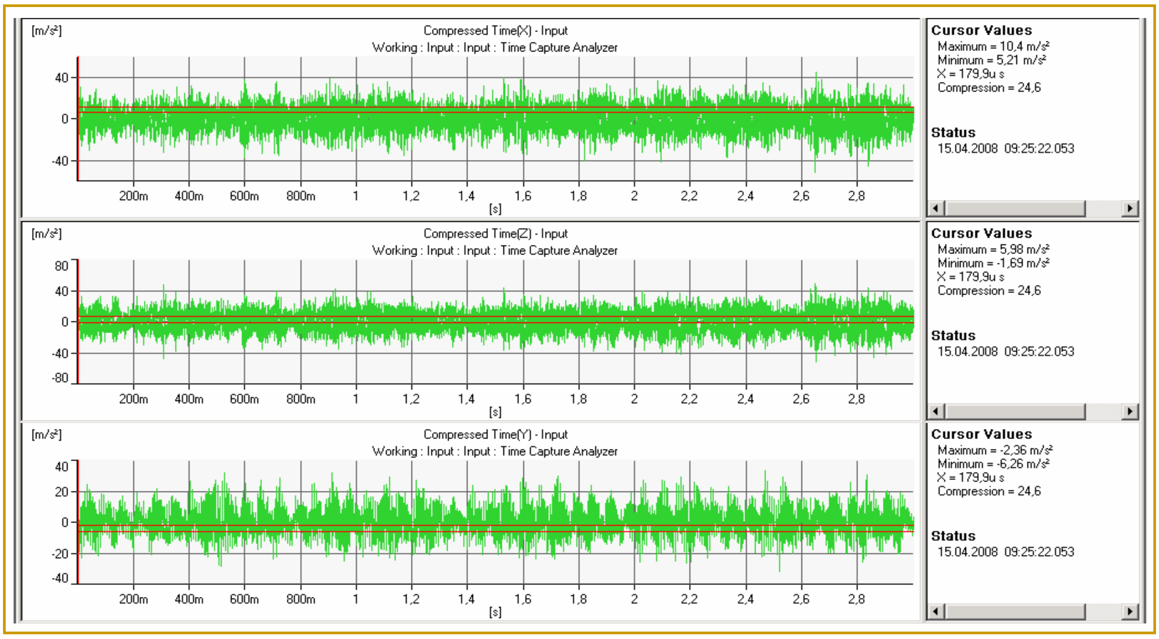


Figure 8-35: Oscillation diagrams with vibration width level 15.

f) The LMS runs with no vibration (after shutting down the vibrating screen)

The most fluctuations occur in picture (e), where the vibrating amplitude is on level 15. This vibration amplitude is of course much more than in the real working conditions. Anyhow the fluctuations are not critical for this work. Diagram “a" shows the LMS scanning lines while the vibrating screen is off. Diagrams “b” and “f” represent the LMS vibration by choosing the “0” oscillation width level.

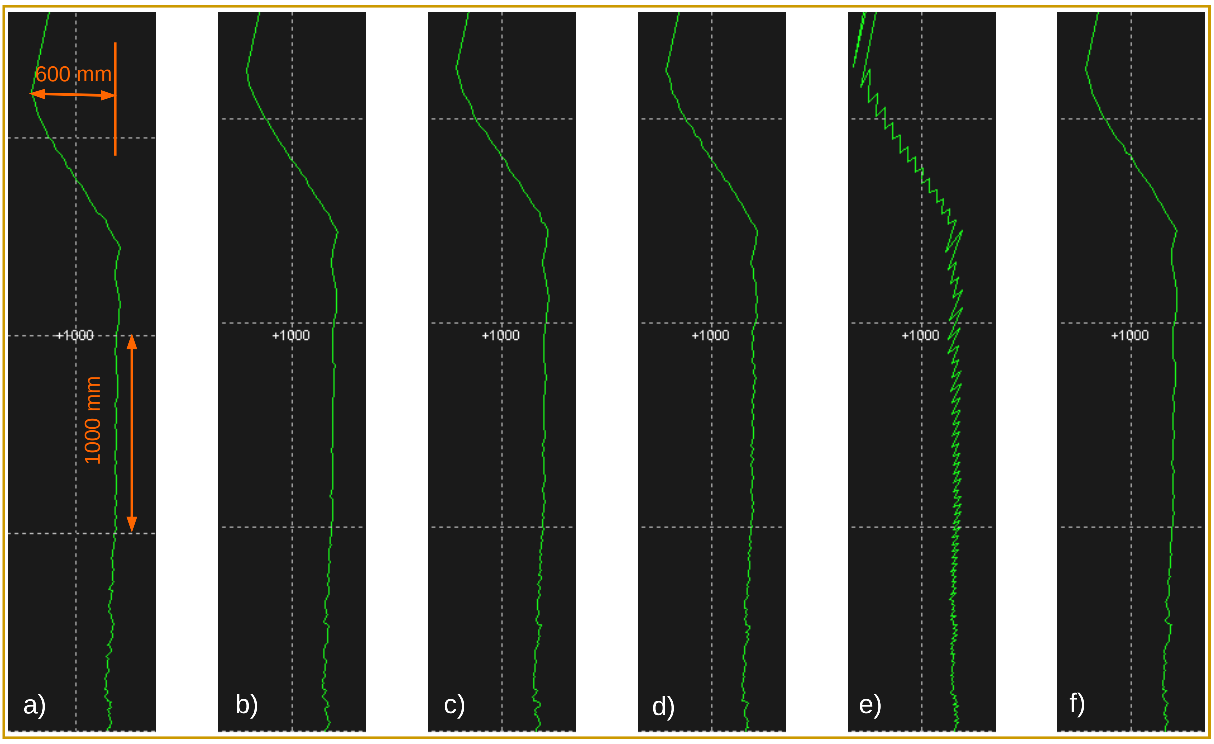


Figure 8-36: LMS vibrating test.

The vibration of the sensor has been measured via a triax accelerometer (for 3 seconds per oscillation type) shown in Figure 8.37.

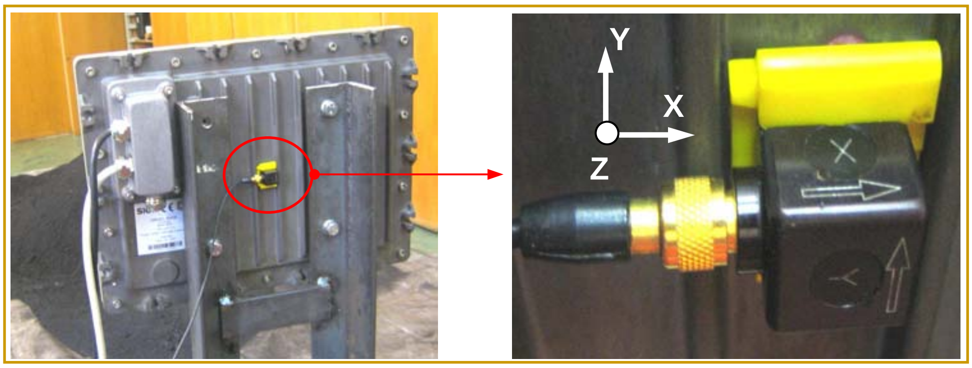


Figure 8-37: Vibration measuring process via triax accelerometer.

8.8.4 Climatic Exposure Test Cabinet (conditioning cabinet)

Putting the device in the conditioning cabinet (Figure 8.38) to bring it to high and low temperatures is the prerequisite for the next LMS test. By carrying out of these tests, it makes it sure, that the sensor can work reliably under rough conditions. For example in hot summer days in Australia or Africa under direct sunlight and in cold and icy winter nights in north countries or in desert. Of course humidity can always be a problem for electronically devices. For that reason the device has been also proofed with 98% humidity for a period of 24 hours.

Figure 8-38: Conditioning cabinet.

8.8.4.1 High temperature and moisture test

The following graphs (Figure 8.39) show the results of vibrating test after a period of 24-hour temperature and moisture test (+ 50 ℃ / 98%). The graphs indicate no difference for different vibrating tests.

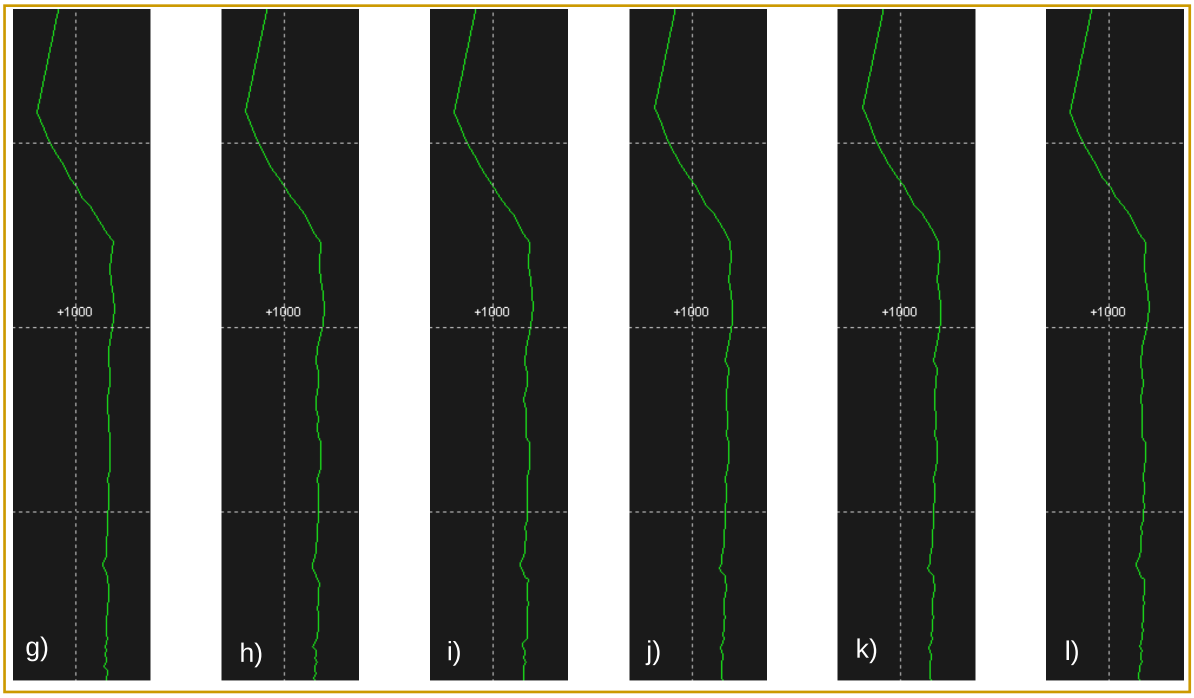


Figure 8-39: LMS graphs after high-temperature test.

8.8.4.2 Low Temperature Test

The same test has been carried out after putting the sensor in the conditioning cabinet with the temperature of - 40 ℃ (Figure 8.40).

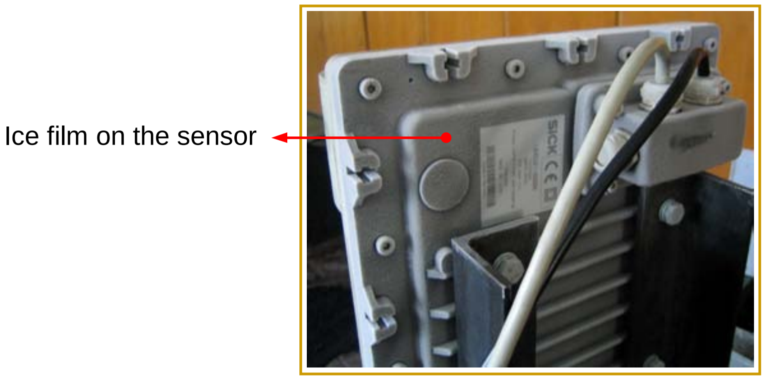


Figure 8-40: Frozen LMS after Low-temperature test.

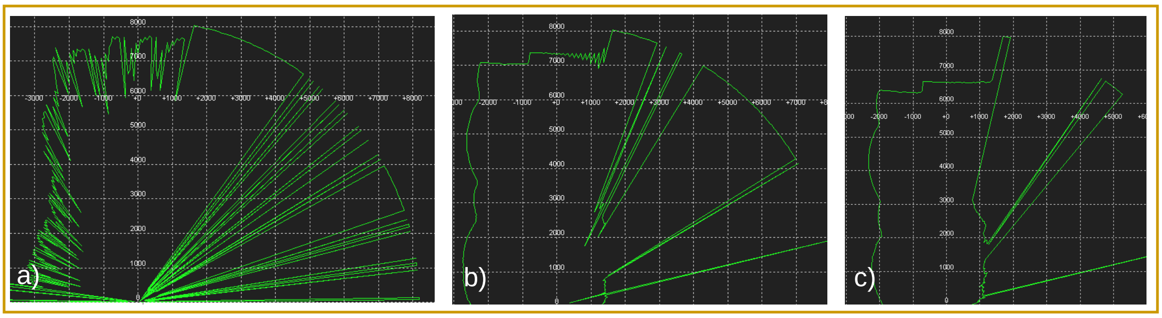


Figure 8-41: LMS scan lines after cooling down (lens not cleaned).

Figure 8.41 shows the changes in the scan lines which have been observed after:

a) two minutes after the LMS removal from the conditioning cabinet

b) after five minutes (cleaned lens)

c) after fifteen minutes

The following graphs have been observed after 30 min. The right print screen (Figure 8.42 R) has been taken after cleaning the lens one minute later.

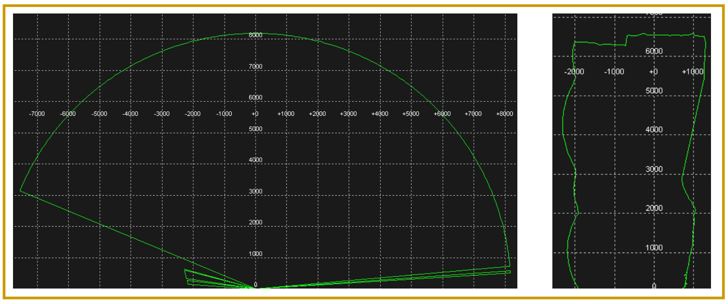


Figure 8-42: LMS scan lines after cooling down L) lens not cleaned R) lens cleaned.

The following graph has been observed after 40 min. The right Figure (Figure 8.43 R) has been printed from the pc display after cleaning the lens one minute later.

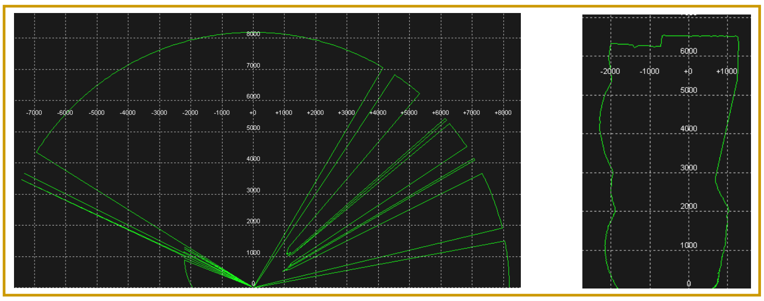


Figure 8-43: LMS scan lines after cooling down L) lens not cleaned R) lens cleaned).

After 50 minutes the laser sensor begins again to work normally. The following graph shows the first one which has been printed in stationary mode (Figure 8.44 m).

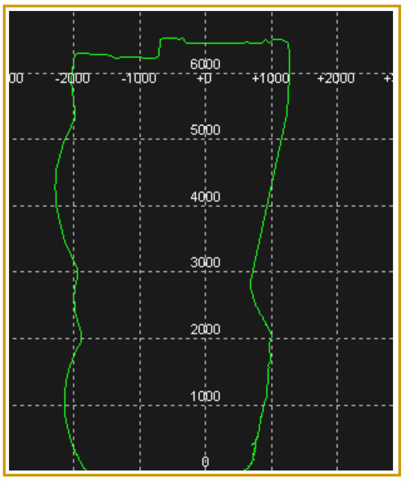


Figure 8-44: m) Device under no vibration.

Following diagrams represent the normal vibrating test after about an hour from device removal out of conditioning cabinet.

m, n, o, p represent vibrating width levels with 0,5,10,15 and q represents a graph without vibration.

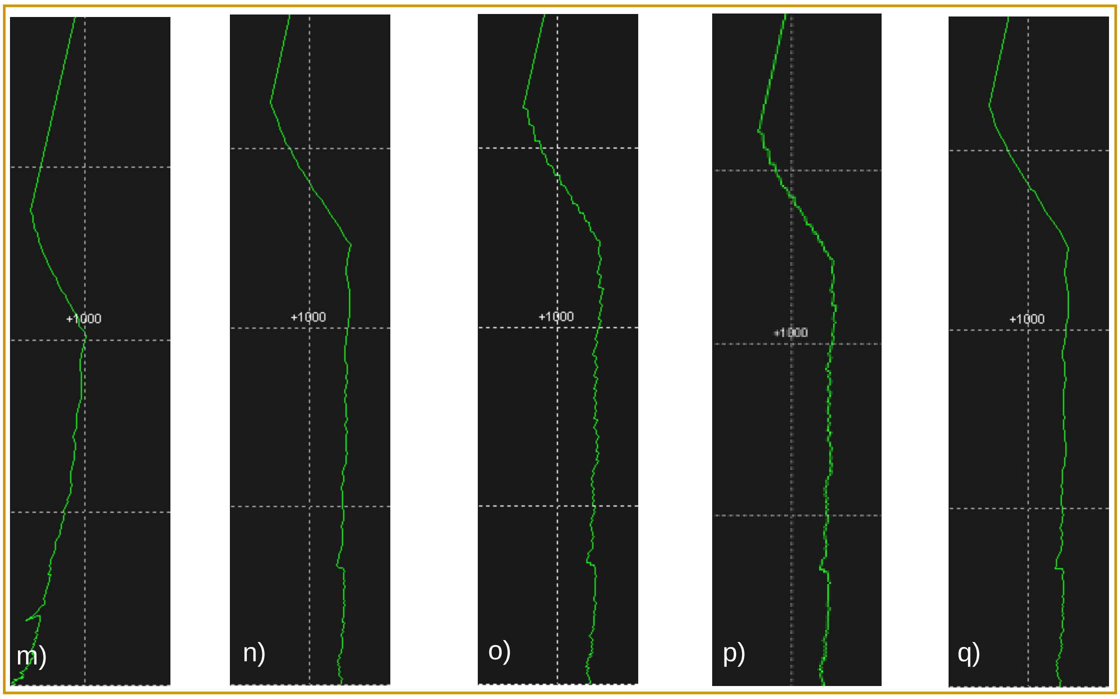


Figure 8-45: LMS scan lines after cooling down.

8.8.5 Desert Simulation

The results of the desert simulation with putting the Laser sensor in the conditioning cabinet for a period of 72 hours (3 days) with an alternatively temperature changes (+50 ℃, -40 ℃), are shown in Diagram 8.4. The similarity of the graphs is a proof for the reliability of the device against such these alternatively extreme weather changes.

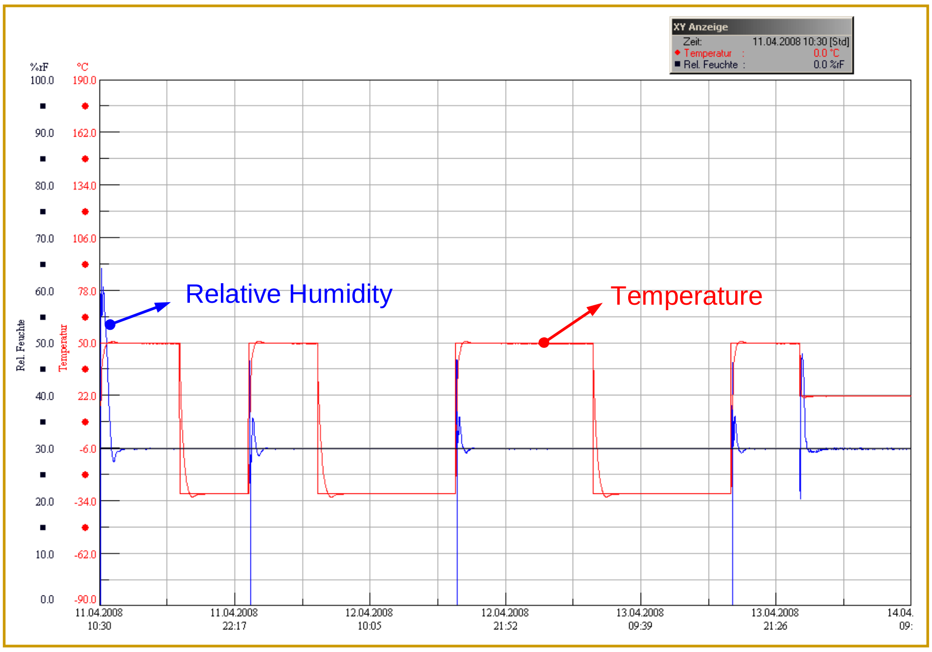


Diagram 8-4: Temperature and moisture diagram for desert simulation.

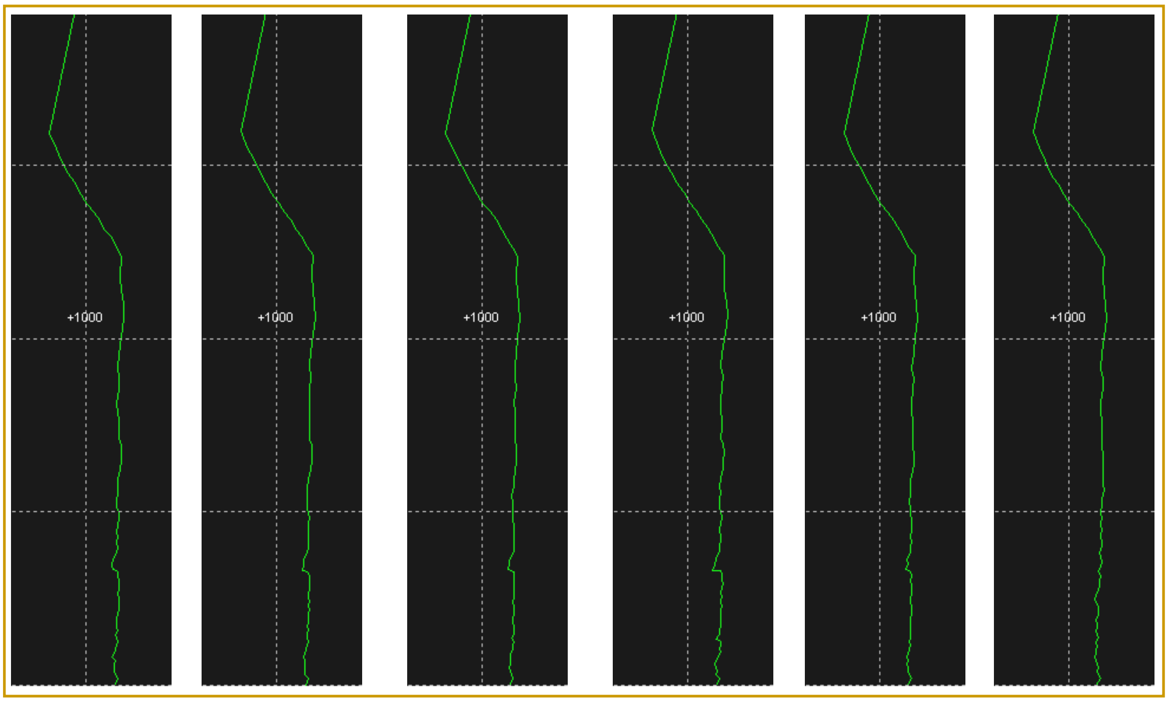


Figure 8-46: Laser sensor desert simulation.

The Diagram 8.4 shows the Temperature and moisture diagram of the conditioning cabinet which makes a comparison between the set- and actual values which have measured in a period of three days.

8.8.6 LMS - Dust Sensitivity Test

Finally after all high-, low temperature, humidity, oscillation, direct beam reflecting (via mirror) and desert simulation, it is time for simulating and carrying out the most important test on the device, the dust sensitivity test (Figure 8.47), because cloud of dust is the main problematic for the optic sensors.

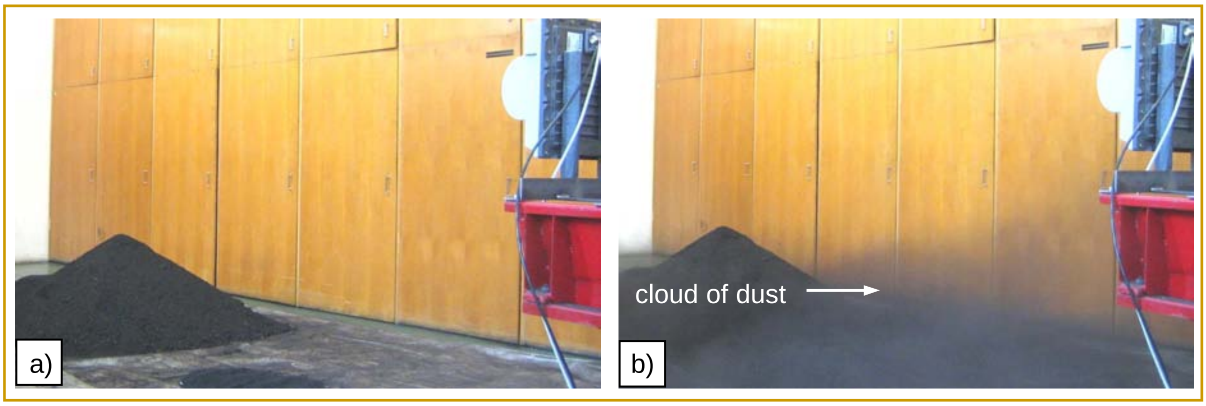


Figure 8-47: LMS- Dust sensitivity test.

Following print screen shows the influence of cloud of dust on the sensor. The diagrams are parts of video clip which has been recorded with the help of the camstudio-software. The test has been carried out while increasing the oscillation amplitude from vibrating width 0 to vibrating width 15. Diagram No. 5 shows the worse possible situation with a deflection of ~ 200 mm.

Diagram 1: normal condition

Diagram 2: presence of cloud of dust

Diagram 3: thick cloud of dust after throwing the coal on the floor

Diagram 4: short time after deposition of dust

Diagram 5: after the second bulk throw

Diagram 6: thick cloud of dust after throwing the coal on the floor

Diagram 7: normal condition

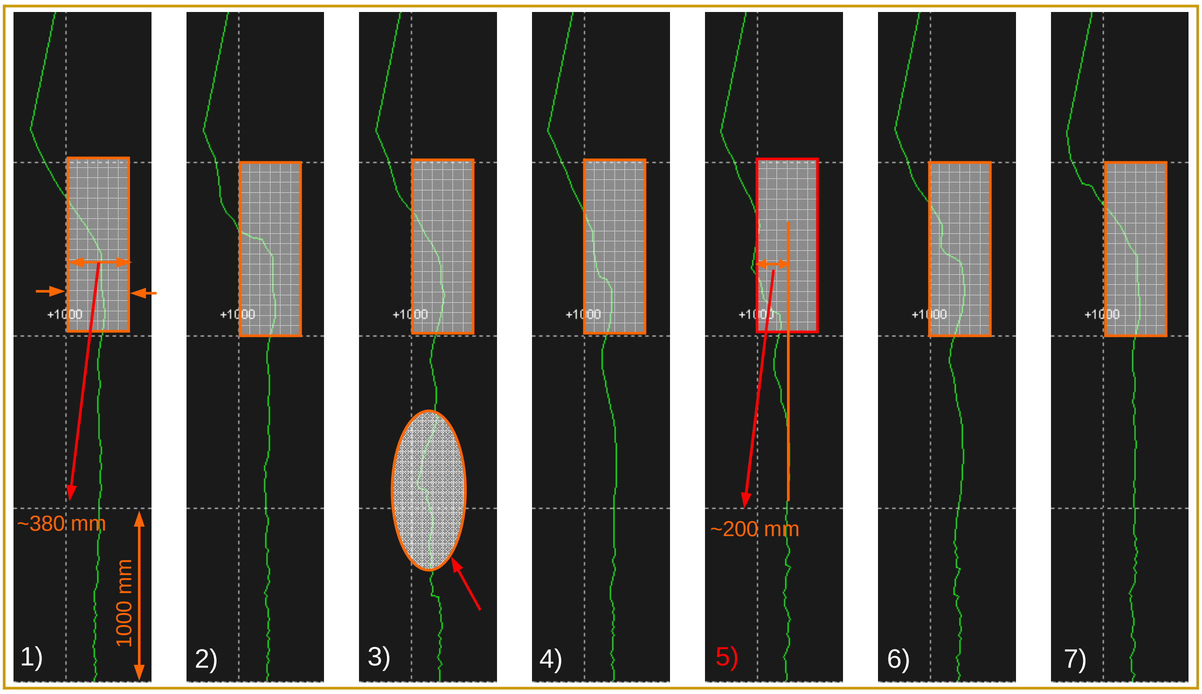


Figure 8-48: Dust sensitivity test diagrams.

8.8.7 Reflecting test

The reflecting test has been also fulfilled with the help of a mirror located in front of the device (~ 5 m distance). The reflecting phenomena can occurs when the device operating near water (river, sea …) or by passing a vehicle near the device. As shown in Figure 8.49, the direct reflecting of the beams has no influence on the measuring process. Figure "a" shows the front side (reflecting side) of the mirror and Figure "b" the back side of the mirror.

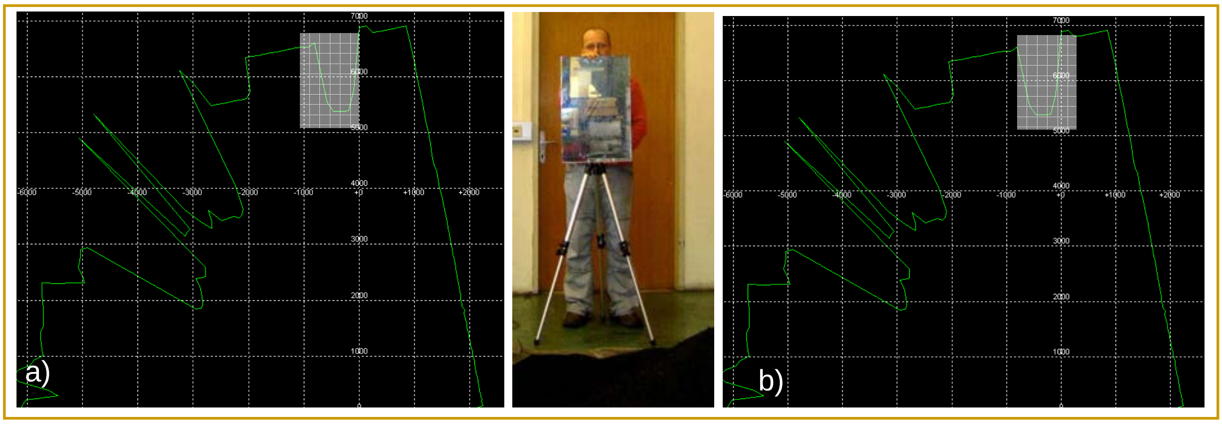


Figure 8-49: LMS reflecting test.

8.9 Results (Summary of Experiments)

The Laser sensor with the following hardware / software specifications has been used for the tests:

Laser type and specifications	LMS 221, 24 V, 1.8 A
Scanning angle	180°
Scanning resolution	1°(optional for this work)
Times of scanning	13 ms
Range of scanning	8 m (optional for this work)

Table 8-4: LMS specifications for this work.

The bulk material used for the experiments with the following attributes:

Bulk material	Canadian coal
Angle of repose	108°
Grain size	0 - 3,15mm….70.13 % 7.5 - 10 mm…4.20 % 10 - 20 mm….7.41 % > 20 mm…….2.63 %

Table 8-5: Bulk material specification used for this work.

- Coal dome test

The reaction of the laser sensor to the color and the grain size of the bulk material, as well as the distance of the LMS to the coal dome have been proved in the first step. Rapid reactions of the device to the changes in the defined field are very important for the collusion protection purposes which have been observed in the tests.

- Oscillation test

After making sure that the sensor works reliably with the defined conditions, it is time for simulating the real working conditions. For that purpose all of the following tests and experiments have been done while the LMS is running on a vibrating structure (here, a vibrating screen).

- High temperature & humidity test

The LMS has shown a very good resistance against putting the device in the conditioning cabinet for 24 hours with a temperature of +50 ℃ and a relative humidity of 98%.

- Low temperature test

The low temperature test (-40 ℃) was not as successful as the high temperature test in the first 30 minutes after running the device. Steam up of the lens is the main problem. The in-built mirror of the device could be damaged in very low temperatures. It is recommended to use a heater (company made) for preventing the hazard.

- Desert simulation

The LMS has shown a very good resistance against the +50 ℃ / -40 ℃ alternating temperature treatment for a period of 72 hours. The graphs show the working condition of the LMS with different oscillating amplitudes after bringing it out of the conditioning cabinet in room temperature.

- Dust sensitivity test

Cloud of dust is a very important factor for the working-site-simulation of the LMS. Cloud of dust is always present when the handling material is a dry bulk good (e.g. coal mine in Australia). A very small change on the graphs is a proof of the device reliability.

- Direct reflection test

Reflecting of the sending beam directly to the lens because of the see water or passing cars etc. could influence the LMS. Direct reflection test as the final test has been carried out with the help of a flat mirror holding opposite of the lens with a distance of ~ 5 m. The graphs show no influence on the LMS running with different oscillating amplitudes.

9. CONCLUSION

Collision protection between the conveyor boom of a stacker or reclaimer and the bulk material as the main purposeful problem-treatment in this work has been discussed by the way of analysing different anti-collision possibilities. Laser system has been chosen (among Ultrasonic, Microwave and Laser systems) for this purpose after comparing the advantages and disadvantages of the systems discussed in chapter 8.4 in this work. LMS or laser measurement system is the suitable solution for the purpose of collision protection on stackers and reclaimers. Compatibility of the sensor to the mechanical and environmental restrictions has been also proved by the means of some tests and experiments. For that reason the following tests has been carried out as explained in 8.8, like as:

- Coal dome test,
- LMS oscillation test (with 4 different vibrating width levels),
- High temperature & humidity test (+50 ℃ / 98% humi dity for 24 h),
- Low temperature test (-40 ℃ for 24 h),
- Desert simulation (alternating high / low temperature for 72 h),
- Dust sensitivity test and finally,
- Reflection test (direct reflection of the laser beams via a flat mirror).

The laser sensor has proved a high withstand against the extreme conditions (vibration and temperature variations) and delivered accurate measured values during the tests fulfilment, except by the low temperature test, which it took about an hour for working normally again. In order to prevent damaging the built-in mirror or electrical devices, use of an external heater (company made), is recommendable before driving the device up and even during the working hours in very cold conditions.

Dust sensitivity test of the sensor is also acceptable, but in extreme dusty conditions, use of the high pressure housing (company made) would also be suggested. Using the company made weather protection hood (Figure 8.22) is not only a protective device for the dust but also for rain drops.

The laser sensor has also passed the desert simulation (alternating high / low temperature from + 50 to - 40 ℃ for a period of 72 h) successfully .

The reflection test, which has been fulfilled with a use of a flat mirror with a distance of about 5 meters from the device, didn't have any influence on the sensor functionality.

Mounting a sensor on each side of the boom and defining the active fields along the boom, secures the collision protection between the boom and the stockpile (see 8.6, four proposal LMS arrangements). Definition of two fields (inner and outer fields, Figure 8.27) guarantees a high precaution so that the disturbing of the outer filed brakes down the machine and disturbing the inner field stops the machine in a short time.

The laser sensor with an IP-code of 67 is protected against dust and water[1]. It is not allowed to use the LMS in conditions with a temperature of more than 70 ℃ and less -30 ℃.

Checking the drying agent cartridge every 4 to 5 years and in shorter periods of time in humid atmosphere ensures a longer life span for the LMS.

The laser measurement system (LMS) as an accurate device, with a high withstand against different climate conditions, having the possibility of measuring area programming and definition of working field, can be used on bulk materials handling machinery for the purpose of collision protection between the machine and the stockpile. The machines equipped with LMS-sensors are able to work in different climate conditions, for example in desert (high temperature), near sea and rivers (reflecting effect), in north countries with icy winters (Low temperature) or by handling of dry and dusty materials (cloud of dust). Of course some auxiliary devices (company made) mentioned in this work, would be also recommended in order to get the best efficiency and result from the device in different atmospheric conditions. In this way it was possible, in the scope of this work, to make a clear recommendation for the use of such an LMS system for the future applications of the company Sandvik.

[1)] IP-code

6 → Totally dust protection

7 → up to 1 m of submersion in water (for a short time)

Appendix

CONVERSION FACTORS

MASS

1 kg = 2.2046 lb

POWER

1 W = 1 J/s = 860.42 cal /h
1 hp = 745.7 W = 550 ft-lb/s
1 kW = 1X103 W

LENGTH

1 in. = 2.54 cm = 25.4 mm
1 m = 3.208 ft = 39.37 in.
1 km = 0.612 miles
1 mile = 5280 ft

ENERGY

1 J = 1 N m = 1X107 ergs
1 erg = 1 dyn cm
1 cal = 4.1855 J

ROTATION

1 rev/s = 2 π rad/s = 60rpm

VISCOSITY

1 N s/m2 = 0.672 lb/ft s

FREQUENCY

1 Hz = 2 π rad/s

MOMENT OR TORQUE

1 N m = 0.7376 lb ft

THE GREEK ALPHABET

Alpha	Α	α	**Iota**	Ι	ι	**Rho**	Ρ	ρ
Beta	Β	β	**Kappa**	Κ	κ	**Sigma**	Σ	σ
Gamma	Γ	γ	**Lambda**	Λ	λ	**Tau**	Τ	τ
Delta	Δ	δ	**Mu**	Μ	μ	**Upsilon**	Υ	υ
Epsilon	Ε	ε	**Nu**	Ν	ν	**Phi**	Φ	φ
Zeta	Ζ	ζ	**Xi**	Ξ	ξ	**Chi**	Χ	χ
Eta	Η	η	**Omicron**	Ο	ο	**Psi**	Ψ	ψ
Theta	Θ	θ	**Pi**	Π	π	**Omega**	Ω	ω

Technical Data: AVSA 002

Main Dimensions	
Total weight	135 t
Total length	12 m
Height over canopy	4.9 m
Width over loading table	7.5 m
Ground pressure	0.23 MPa
Electrical system 1000V / 50 Hz	
Total installed electric motor power	653 kW
Cutter Motor	270 kW
Cutting Profile / Boom Telescope Extended / Retracted	
Height	4.9 m / 5.7 m
Width	7.0 m / 7.5 m
Negotiable Gradients	
Without machine support	+/- 15 gon
Speed of cutter head	1.4 m / s
Tramming speed	0 – 5 m / min
Power Demand	
Via transformer	1200 kVA
Via generator set	1500 kVA
Conveying System	
Double chain conveyor motor (electric)	36 kW
Capacity of conveyor	max 400 m3 / h

Sandvik Mining and Construction, Zeltweg-Austria

Technical Data: MT 720

Main Dimensions	
Total weight	135 t
Total length	18.2 m
Height over canopy	4.8 m
Width over loading table	4.56 m
Ground pressure	0.23 MPa
Electrical system 1000V / 50 Hz	
Total installed electric motor power	555 kW
Cutter Motor	300 kW
Cutting Profile / Boom Telescope Extended / Retracted	
Height	6.6 m / 6.1 m
Width	9.1 m / 8.4 m
Negotiable Gradients	
Without machine support	+/- 20 gon
Speed of cutter head	1.4 m / s
Tramming speed	0 – 15 m / min
Power Demand	
Via transformer	1200 kVA
Via generator set	1500 kVA
Conveying System	
Double chain conveyor motor (hydraulic)	90 kW
Capacity of conveyor	max 400 m3 / h

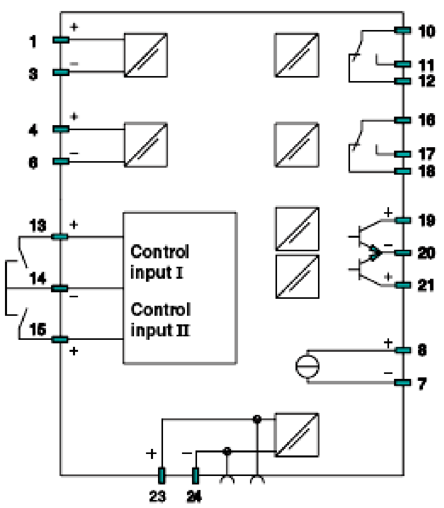
Sandvik Mining and Construction, Zeltweg-Austria

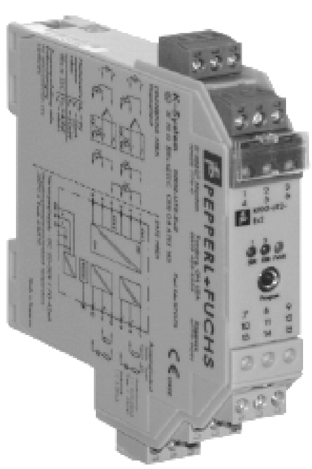
Technical Data: LMS 211-30206

Angular resolution	1 ... 0.25 °
Response time	13 ... 52 ms
Resolution	10 mm
Systematic error	+/- 35 mm, +/- 5 cm
Statistical error (1 sigma):	10 mm
Laser class	1
Enclosure rating	IP 67
Ambient operating temperature	-30 ℃ ... +50 ℃
Scanning range	80 m
Data interface	RS-232, RS-422
Data transmission rate	9,6 / 19,2 / 38,4 / 500 kBaud
Switching outputs	2 x relay/1 x PNP, 3 x PNP
Supply voltage	24 V DC +/- 15%
Current consumption	20 W
Heater current rating	6 A
Storage temperature	-30 ℃ ... +70 ℃
Weight	9 kg
Dimensions (L x W x H)	195 x 352 x 266 mm

Technical Data: Frequency converter

Connection	Terminals 23,24
Rated voltage	20…90 V DC / 48…253 V AC 50…60 Hz
Rated current	Approx. 130 mA
Power loss	2.2 W / 3.5 VA
Power consumption	2.5 W / 4 VA
INPUT	
Connection	Input I: terminals 1+ , 3- Input II: terminals 4+ , 6- Input III: terminal 13+ , 14- (control input 1) Input IV: terminals 15+ , 14- (control input 1)
Open circuit voltage / Short circuit current	8.2 V / 10mA
Input frequency	Slip monitoring 10…1000 Hz
OUTPUT	
Connection	Output I: terminals 10,11,12 Output II: terminals 16,17,18 Output III: terminals 19+ , 20- Output IV: terminals 21+ , 20- Output V: terminals 7-, 8+
Mechanical life	5 x 107 switching cycle
Resolution	Slip monitoring: 1% frequency measurement: 0,1 % of measured value; but > 0.001 Hz
Accuracy	Slip monitoring: 1% frequency measurement: 0,5 % of measured value; but > 0.001 Hz
Protection degree	IP 20





Pepperl+Fuchs GmbH

DEFINITION OF NEW TERMS

A/D converter	A device, which converts an analog voltage into a digital number.
Accelerometer	An instrument for measuring acceleration.
Accuracy	The closeness with which a measuring system indicates the actual value.
Bimetallic thermometer	A temperature measuring device that utilizes differential thermal expansion of two materials.
Bus	The main computer line used to transmit information.
Calibration	The act of applying a known input into a system to observe the system output.
Conversion error	The errors associated with converting an analog value into a digital number.
Error	Difference between the value indicated by a measurement system and the actual value measured.
Hysteresis	The difference in the indicated value for any particular input when that input is approached in an increasing input direction versus when approached in a decreasing input direction.
Input	Process information sensed by the measurement system.
Junction	For thermocouples, an electrical connection which measures temperature.
Load cell	Sensor for measuring force or load; a variety of principles may be employed.
LVDT	Linear Variable Differential Transformer: A sensor/transducer that provides an emf output as a function of core displacement.
Noise	An extraneous effect that imposes random variations on the measured signal.
Ohmmeter	An instrument for measuring resistance.
Peltier effect	Describes the reversible conversion of energy from electrical to thermal at a junction of dissimilar materials through which a currents flow.
Potentiometer	Refers to a variable resistor, or to an instrument for measuring small voltages with high accuracy.
Potentiometer transducer	Variable electrical resistance transducer for measurement of length or rotation angle.
Proving Ring	An elastic load cell, which may be used as a local calibration standard.
Quantization	Process of converting analog value into a digital number.
Range	The lower to upper limits of an instrument or test.
Repeatability	Precision claim based on multiple tests within a given lab on a single unit.
Resistivity	Material property describing the electrical resistance of a material.
Resolution	The smallest detectable change in measured values indicated by the measuring system.
Seebeck effect	Source of open circuit emf in thermocouple circuits.
Seismic transducer	Instrument for measuring displacement in time, velocity or acceleration; based on a spring-mass-damper system.
Sensitivity	The rate of change of a variable (y) relative to a change in some other variable (x), for example, dy/dx.
Sensor	The portion of the measurement system that senses or responds directly to the process variable being measured.
Serial communication	Communication that transmits information one bit at a time.
Span	The difference between the maximum and minimum values of operating range of an instrument.

Strain	Elongation per unit length of a member subject to an applied force.
Stress	Internal force per unit area. These internal forces maintain in equilibrium the applied external forces.
Thermistor	Temperature-sensitive semiconductor resistor.
Thermocouple	Junction of two similar conductors used to measure temperature.
Thomson effect	Describes the creation of an emf through a temperature difference in a homogeneous conductor.
Time delay	The delay or lag between an applied input signal and the measures output signal.
Wheatstone bridge	Electrical circuit for measuring resistance with high precision; can be used to measure static or dynamic signals.

LMS TERMINOLOGY

English	Deutsch
Scanning range	Reichweite
Angular resolution	Winkelauflösung
resolution	Auflösung
Systematic error	Systematischer Fehler (1Sigma)
Supply voltage	Versorgungsspannung
Laser class	Laserklasse
Data interface	Datenschnittstelle
Switching outputs	Schaltausgänge
Data transmission rate	Datenübertragungsrate
Response time	Ansprechzeit
Enclosure rating	Schutzart
Operating temperature	Betriebstemperatur
Storage temperature	Lagertemperature
Power consumption	Leistungsaufnahme
Heater current rating	Strombedarf Heizung
weight	Gewicht
Dimensions	Abmessungen (L x B x H)

http://*www.sick.com*

LASER MEASUREMENT SYSTEM (LMS)
(Glossary of Terms)

Monitoring fields	Freely configurable, two dimensional zones (areas). If a detected object is in a particular zone (field infringement) the LMS changes the signal level at the associated switching output. This means that the LMS switches the statical signal from typical 24 V DC (high) to signal ground (low). In contrast, special devices with relay outputs (normal position: contact closed) opens the external circuit.
Field set	A field set comprises max. 3 configurable monitoring fields (Field A, B, C). The LMS can store 2 field sets.
Field set switching	Change between the two field sets in the LMS. When starting the system always field set 1 is active. Switching the field set 2 takes place via the restart input using a statical 24 V DC-signal or using a command (telegram) via the data interface.
Field infringement	An object is detected within a specified monitoring field.
Field, teach-in	Instead of configuring a segmented field the data can be tough in. The LMS defines its entire free field of vision as monitoring area. The field limits follows the environment contour precisely. Field areas that are not required can be deleted manually.
Field, subtractive	Allows a zone to be monitored that is the space remaining when field B deducted from field A. Special devices for security applications can operate with max. 2 subtractive fields.
Field, temporary	A field form can be defined and activated by external data information, transfer time to the LMS is about ca. 200 ms (temporary because when the power supply is removed, the field is lost).
Blanking	Is set in cm as the so-called blanking factor. The blanking factor defines the minimum object size (depends on distance) that can lead to registration at the switching outputs. In the area monitoring, the blanking is only possible in conjunction with scan-oriented evaluation (not in conjunction with pixel-oriented evaluation).
Field evaluation	To prevent erroneous switching causes by particles, etc. the LMS evaluates the fields using various processes (scan-oriented or pixel-oriented, always in conjunction with multiple reading)

Field evaluation, scan-oriented	With scan-oriented evaluation the LMS stores and verifies a field infringement (at any particular location) using multiple readings. If the LMS registers further infringements in subsequent scans in the field (at any particular location) the signal level at the associated switching output changes after the number of multiple readings defined have elapsed.
Field evaluation, pixel-oriented	In contrast to the scan-oriented evaluation, the LMS evaluates every single beam in pixel-oriented mode. If further infringements occur consecutively at the same beam position, the signal level at the associated switching output changes. This method is best suited for increasing availability in rain or snow.
Contour as reference	Using this function the LMS monitors the surrounding area (background) of a monitored field. This means that an object's existence (e.g. house wall) is constantly being verified. If the contour ceases to be registered the corresponding switching output changes the signal level even without any infringement of a field. The range of validity of the reference contour can be set as desired. The function can also be used to prevent sabotagte.
Restart	*Automatic*: The associated field switching output is activated as soon as the field becomes clear. *After delay:* The associated field switching output is activated after a set time delay has elapsed (when the field is clear). *With button:* The associated field switching output is activated when the external button is actuated (when the field is clear).

http://*www.sick.com*

GLOSSARY OF LASER TERMS

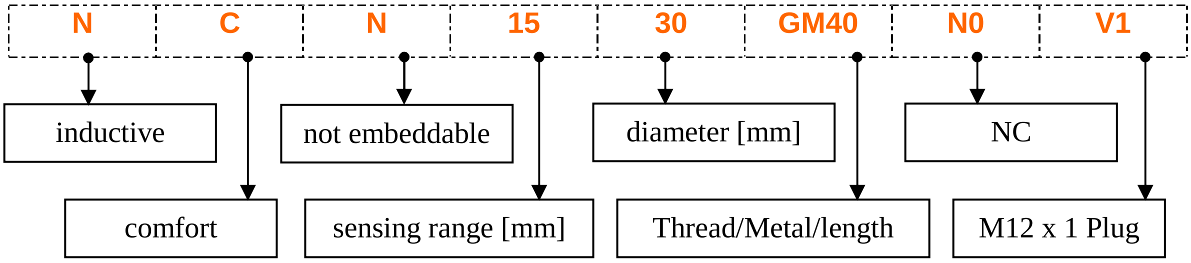
Absorption	Transformation of radiant energy to a different form of energy by the interaction of matter, depending on temperature and wavelength.
Absorption coefficient	Factor describing light's ability to be absorbed per unit of path length.
Active medium	Collection of atoms or molecules capable of undergoing stimulated emission at a given wavelength.
Aiming beam	A laser (or other light source) used as a guide light. Used coaxially with infrared or other invisible light may also be a reduced level of the actual laser used for surgery or for other applications.
Amplification	The growth of the radiation field in the laser resonator cavity. As the light wave bounces back and forth between the cavity mirrors, it is amplified by stimulated emission on each pass through the active medium.
Angstrom	A unit of measure of wavelength equal to 10-10 meter, 0.1 nanometer, or 10-4 micrometer, no longer widely used nor recognized in the SI system of units.
Anode	An electrical element in laser excitation which attracts electrons from a cathode.
Aperture	An opening through which radiation can pass.
Beam	A collection of rays that may be parallel, convergent, or divergent.
Beam divergence	Angle of beam spread measured in radians or milliradians (1 milliradian = 3.4 minutes-of-arc or approximately 1 mil). For small angles where the cord is approximately equal to the arc, the beam divergence can be closely approximated by the ratio of the cord length (beam diameter) divided by the distance (range) from the laser aperture.
Cathode	A negatively charged electrical element providing electrons for an electrical discharge.
CO_2 Laser	A widely used laser in which the primary lasing medium is carbon dioxide gas. The output wavelength is 10.6 micrometers in the far infrared spectrum. It can be operated in either CW or pulsed.
Coherence	A term describing light as waves which are in phase in both time and space. Monochromaticity and low divergence are two properties of coherent light.
Collimated light	Light rays that are parallel. Collimated light is emitted by many lasers. Diverging light may be collimated by a lens or other device.
Convergence	The bending of light rays toward each other, as by a positive (convex) lens.
Diffraction	Deviation of part of a beam, determined by the wave nature of radiation and occurring when the radiation passes the edge of an opaque obstacle.
Divergence	The increase in the diameter of the laser beam with distance from the exit aperture. The value gives the full angle at the point where the laser radiant exposure or irradiance is 1/e or 1/e2 of the maximum value, depending upon which criterion is used.
Incident light	A ray of light that falls on the surface of a lens or any other object. The

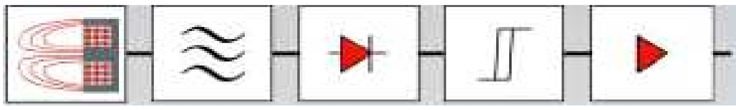
	"angle of incidence" is the angle made by the ray with a perpendicular (normal) to the surface.
Infrared radiation (IR)	Invisible electromagnetic radiation with wavelengths which lie within the range of 0.70 to 1000 micrometers.
Integrated radiance	Product of the exposure duration times the radiance. Also known as pulsed radiance.
Intensity	The magnitude of radiant energy.
Laser	An acronym for light amplification by stimulated emission of radiation. A laser is a cavity, with mirrors at the ends, filled with material such as crystal, glass, liquid, gas or dye. A device which produces an intense beam of light with the unique properties of coherence, collimation and monochromaticity.
Modulation	The ability to superimpose an external signal on the output beam of the laser as a control.
Monochromatic light	Theoretically, light consisting of just one wavelength. No light is absolutely single frequency since it will have some bandwidth. Lasers provide the narrowest of bandwidths that can be achieved.
Nd: glass laser	A solid-state laser of neodymium: glass offering high power in short pulses. A Nd doped glass rod used as a laser medium to produce 1064 nm light.
Pulse repetition frequency (PRF)	The number of pulses produced per second by a laser.
Semiconductor laser	A type of laser which produces its output from semiconductor materials such as GaAs.
Spot size	The mathematical measurement of the radius of the laser beam.
Stimulated emission	When an atom, ion, or molecule capable of lasing is excited to a higher energy level by an electric charge or other means, it will spontaneously emit a photon as it decays to the normal ground state. If that photon passes near another atom of the same energy, the second atom will be stimulated to emit a photon.
Threshold	The input level at which lasing begins during excitation of the laser medium.
X-Ray laser	A device that uses stimulated emission to produce coherent X rays.
YAG (Yttrium Aluminium Garnet)	A widely used solid-state crystal which is composed of yttrium and aluminium oxides which is doped with a small amount if the rare-earth neodymium.

http://www.chem.purdue.edu.com

INDUCTIVE SENSOR

(FUNCTION DESCRIPTIONS AND DEFINITIONS)



Principle	The principle of inductive proximity sensors is based on the interaction between metallic conductors and an electromagnetic alternating field. Eddy currents are induced in the metallic damping material, which removes energy from the field and reduces the height of the oscillation amplitude. This change is processed in the inductive sensor, which change its output state accordingly.
Function groups	 Field, coil Oscillator Demodulator Trigger Output driver
Active surface	…is the area through which the high-frequency sensor field enters the air gap. It is determined primarily by the base of the shell core and corresponds roughly to the surface area of the shell core cap.
Frequency of operating cycles	…refers to the maximum number of switching operations per second.
Supply voltage	…is the permissible voltage range in which certain operation of the switch is guaranteed.
Voltage drop	…is the voltage measured across the load of a closed sensor at load current.
Ripple σ (%)	…is the AC voltage overlaid on the DC voltage given in percent. To operate DC switches a filtered DC voltage having a ripple of max. 15% is required.

Switching distance	…is the distance between the standard target and the active surface of the proximity switch at which a signal change is generated. For NO this means from OFF to ON and for NC from ON to OFF.
Rated operating distance S_n	…is a theoretical value, which does not take into account manufacturing tolerances, operating temperatures, supply voltages, etc.
Effective operating distance S_r	…is the switching distance of an individual proximity switch as measured under specified conditions.
Useful switching distance S_u	…is the switching distance of a single proximity switch under specified temperature and voltage conditions.
Assured operating distance S_a	…is any switching distance for which an operation of the proximity switch within the permissible operation conditions (temperatures, voltages) is guaranteed.
Response time	…is the time a sensor requires in order to reliably and stably change the output signal. The specified time, which was determined at maximum measuring speed, including both the electrical response time of the sensor and the time for the mechanical change of the damping state.
Temperature coefficient	…describes the deviation of the sensor output under the influence of a temperature change and is therefore a quality criterion of the sensor.

http://www.pepperl-fuchs.com

GERMAN-ENGLISH GLOSSARY

Abstrahlung	radiation
Achse	axis
Anregung	excitation
Ansprechzeit	Response time
Ansteigzeit	Rise time
Auflösung	Resolution
Ausgang	exit
Auslenkung	amplitute, deflection
Ausmaß, Größe	magnitude
Reichweite, Bereich,	range
Berührungslos	contact-free, contactless
Beschleunigung	acceleration
Biegung	bending
Blindwiderstand	reactance
Brückenschaltung	bridge circuit
Dämpfung	damping, absorbability
Dehnungsmessstreifen	strain gauge
Drehmoment	torque, turning moment
Druck	pressure
Druckanzeigegerät	pressure gauge
Durchfluss	flow rate
Durchflusszähler	flow meter
Eigenfrequenz	natural frequency
Electromagnet-ventil	solenoid valve
Empfindlichkeit	sensitivity
Fehler, Störung	error
Fehlerfortpflanzung	error propagation
Fläche	surface
Flachkabel	flat cable
Gehäuse	case, housing
Geräusch	noise
Geschwindigkeit	Velocity
Gleichstrom	direct current (DC)
Größe, Messwert	value
Halbbrücke	half-bridge
Infrarot	Infrared
Intensität	Intensity
Kalibration	calibration
Kapazität	capacity
Kondensator	capacitor
Kraft	force
Kraftaufnehmer	force sensor, load cell
LED	LED (light emitting diode)
LED-Anzeige	LED display
Linearität	linearity

Luftspalt	air gap
Magnetfeld	magnetic field
Messwert	measured value
Überwachung	monitoring
Optisch	optic
Piezoelektrischer Kraftaufnehmer	piezo-electric force transducer
Querschnitt	cross-section
Rückmeldung	response
Schwingung	oscillation, vibration
Spannung	voltage, tension
Spule	coil, reel, solenoid
Strom	current
Temperaturkoeffizient	temperature coefficient
Torsion, Verdrehung	torsion
Transformator	transformer
Überlast	overload
Ultraschall	supersonic
Umgebung	environment
Ventil	valve
Verhältnis, Übersetzung	ratio
Verschleiß	wear
Verteilung	distribution
Vollbrücke	full-bridge
Wechselstrom	alternating current (AC)
Welle	wave
Wellenlänge	wavelength
Widerstand	resistance, resistor
Zeitkonstante	time constant
Zeitverzögerung	time delay
Zelle	cell
Zuleitung	supply, input lead

List of Figures

Sandvik Material Handling, Leoben-Austria (SANDVIK MH)

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List of tables and diagrams

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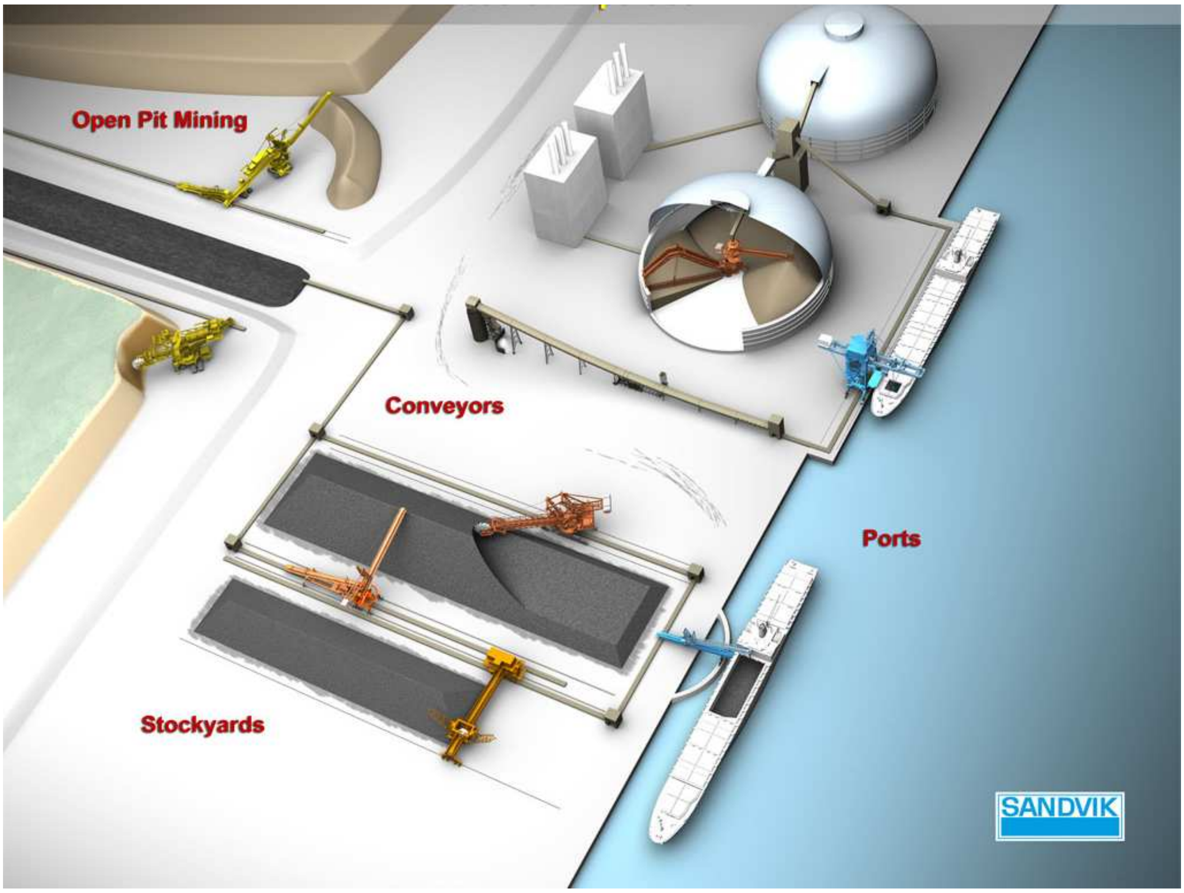


Open-pit mining

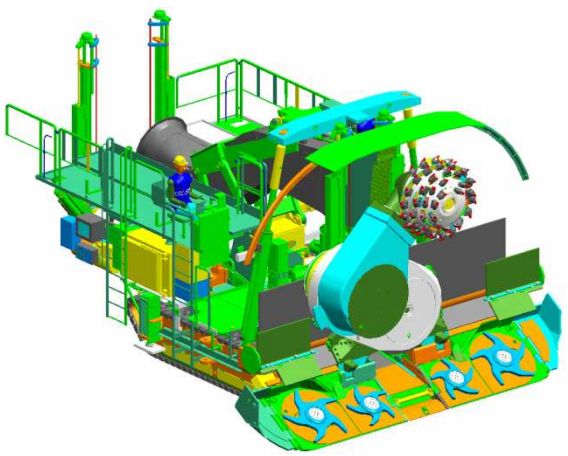
Sandvik Mining and Construction (Leoben - Austria)

Reclaimer

Iron ore Stockyard

Underground mining

Sandvik Mining and Construction (Zeltweg - Austria)



AVSA

ATM (Roadheader)