Sensor selection for monitoring the belt conveying system under laboratory condition

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Preface

This research is a second-year assignment for the master track Transport Engineering and Logistics of Mechanical Engineering of the Delft University of Technology. The assignment is about the sensor selection for a monitoring system of the belt conveyor system located in the laboratory. I would like to thank Dr.Ir. Y. Pang for supervising this research assignment. His knowledge about belt conveyor systems and component parameters was of great importance. I would also like to thank the TU Delft for supporting my research assignment with the test set-up located in the laboratory. Last but not least, I would like to thank the TU Delft for the literature resources and the workplaces to perform this assignment.

Niek Hagen
Delft, 2018
Abstract

A belt conveyor system is a commonly used mean of transportation for dry bulk material. The system components are subjected to wear because of the multiple rotating components. This will result in component failures on the long run. Maintenance or replacement actions are required for these components in order to prevent these system failures. In most cases, maintenance or replacement actions will lead to system downtime. The ambition will be a minimization of the machine downtime in order to keep the production output as high as possible. A monitoring system should be implemented in the belt conveyor system to give more information about the reliability of the components.

Material and methods
The belt conveyor system is located in the laboratory. This conveyor will be used for the sensor selection to monitor the technical and operational condition. Using an extensive literature survey, the major components of the belt conveyor system were selected based on the wear. Subsequently, the parameters were mapped on these components, such as e.g. temperature, tension, speed and vibration. The associated sensors were selected and a sensor location is determined. For this reason, sensors were selected for the main components of the belt conveyor.

Result
A system failure will start in a single part or a composition of components. Not all of the system components are significant for a monitoring system because of negligible failure rate or the small potential consequences in case of a failure. In this literature survey four components were determined for a monitoring system: the belt, idler rolls, pulleys and electric motor. The next step was to determine the parameters of these components. The misalignment of the belt, speed of the belt and the tension on the belt were the main parameters for the monitoring system of the belt. The temperature, acoustic emission and vibration in the bearing were the main parameters for the idler rolls. For monitoring of the technical and operational condition of the bearings, the temperature, vibration and rotational speed were determined in both of the pulleys. The output power of the electric motor was monitored to give more information about the operational condition of the belt conveyor system. Sensors were selected for each of these parameters according to the design requirements of the research project. Last but not least, the location of the sensors was determined for each of the sensors.

Conclusion
To select sensors for technical and operational condition on the belt conveyor system located in the lab, the essential components were chosen: the belt, idler rolls, pulley and electric motor. For each of these components, various system parameters were defined and listed based on the technical and operational condition. For the measurement of these parameters, sensors were selected and the locations were determined. The use of these selected sensors will lead to a higher reliability of the belt conveyor system. It is recommended to converted these sensors into an autonomously functioning monitoring system.
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1. Introduction

Belt conveyor systems are widely utilized for continuous transport of dry bulk materials (i.e. coal, iron ore) over varying distances (Liu, 2016). Most of the components of the belt conveyor are subjected to wear. It is essential to perform maintenance on parts where wear takes place in order to keep the system running (Górniak-Zimroz et al., 2009). Incidental maintenance is not desirable because of the potential high risk of failure during the operation process leading to an unwanted down time. On the other hand, frequent service controls are also not desirable because of the overflowing maintenance costs and unnecessary stoppage of the belt conveyor system. Thus, it is preferred to know the actual state of the system. An overall monitoring system of the significant parts of a belt conveyor system makes this possible. Based on this information, a more relevant maintenance strategy can be applied. An example of a belt conveyor system is shown as a test setup in the laboratory of Delft University of Technology. There are four conveyors located in the laboratory. The goal of this research project is the sensor selection to increase the reliability for the belt conveyor system in the laboratory. High reliability and durability of the transporting machine is required (Mazurkiewicz, 2008). The measurements may deviate from actual belt conveyors, because the conditions in reality might be different from the laboratory conditions. There are more external influences like wind, rain and other circumstances in the industrial environment. However, this will remain outside the scope of the research project. Finally, all described separate parameters will be combined in an overall monitoring system.

The system in the laboratory consists of four belt conveyors oriented in a square. All these four belt conveyors are considered into the sensor selection. The chosen sensors should be applied to the four belt conveyors. A belt conveyor consists of a frame to which all the components are attached. The components attached to the frame of the belt conveyor system located in the laboratory are the idler rolls, pulleys, electric motor, take-up and a gearbox. On each belt conveyor, there is a pulley located at the begin of the belt conveyor and at the end of the conveyor. One of these pulleys is driven by the electric motor. The function of the idler is the support of the belt. The tension on the belt is caused by the take up. To find out the actual state of the system components, the parameters of these components should be defined. Subsequently, the sensors to measure these parameters should be selected. The sensors applied to the system are obliged to some design requirements related to the belt conveyor located in the laboratory. First of all, the original components connect to the test set-up cannot be substituted by replacement parts. Second, a simple sensor installation is obliged for the sensors selected in the assignment. Moreover, for the same parameters, it is desirable to use as many identical parameters as possible. Last but not least, the selected sensors may not exceed the limited budget for the project.
1.1 Goal of the project

The main research question of this project is:

*What sensors can be selected to implement into a monitoring system of the belt conveyor system in the laboratory?*

For the belt conveyor system located in the laboratory, a sensor selection is required to implement into an overall monitoring system to maximize the machine reliability. There are four sub-questions formulated in order to give a legitimate answer to the main question:

1. **What are the main components of the belt conveyor system in the laboratory?**
2. **Which parameters should be monitored?**
3. **Which sensors are selected to measure these parameters?**
4. **What are the locations of the selected sensors on the belt conveyor system in the laboratory?**

1.2 Research methodology

The research assignment of the belt conveyor system located in the laboratory will start with a literature survey about the characteristics of the system components. A comparison between the belt conveyor in general and the specific belt conveyor in the laboratory is made. For the situation in the laboratory, the components in the scope of the project are determined. For these components, the main parameters are established and divided into technical and operational parameters. For each of these parameters, a sensor selection is made according to the design requirements of the project. The locations of the selected sensors are determined according to a practical consideration.
1.3 Outline of the project

The chapters in this report are distributed corresponding to the sub questions of the research project.

**Chapter 1:** The first chapter consist of a general introduction about the research project. In the first chapter, the main question is formulated, divided into four sub questions.

**Chapter 2:** General belt conveyor components are compared to the components located in the laboratory. The scope of the components of the research project is formulated. The components in the scope are further analysed in the assignment.

**Chapter 3:** For the components in the scope of the project, the component parameters are distributed into technical and operational parameters.

**Chapter 4:** For both of the technical and operational parameters of the system components, the sensors are selected according to the design requirements.

**Chapter 5:** Last but not least, the location for each of the selected sensors where determined.

The outline of the project is shown in figure 1.1.

![Figure 1.1: Outline of the project](image-url)
2. Main components of the belt conveyor system

In the industry conveyors are used on large scale in automated distribution and warehousing. A belt conveyor system consists of one or multiple belt conveyors connected to each other. The condition of all the system components should be monitored for a complete analysis. Condition monitoring is defined as the continuous or periodical inspections. The interpretation of these inspections results to indicate the condition of an item (Liu, 2016).

The test set-up in the laboratory is a scaled model of a real belt conveyor system. The belt conveyor system situated in the laboratory, consist of four belt conveyors. All of these belt conveyors consist of a number of components. The reliability of a bulk handling system for example can be defined as the average percentage of time the system's continuous performance is guaranteed (Lodewijks, 2005). A system failure will start in a single part or a composition of components. Therefore, the components are analysed apart from each other. The reliability of the system depends on each of the component’s reliabilities. Though, not all of the single components are equally reliable. In addition, the consequences of the failure will also be dissimilar. For example, a component failure might not directly lead to a system shut down. It is therefore not required to analyse all the failure indicators of each of the components. The set-up located in the laboratory is shown in figure 2.1.

![Belt conveyor system in the laboratory](image)

Figure 2.1: Belt conveyor system in the laboratory

All four of the belt conveyors consist of a number of components, each with their own function. In table 2.1, the components of the belt conveyor are listed with their main functions. These functions are the key performance for the operation of the system.

<table>
<thead>
<tr>
<th>Table 2.1: Components of the belt conveyor in the laboratory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Components</td>
</tr>
<tr>
<td>Belt</td>
</tr>
<tr>
<td>Idler</td>
</tr>
<tr>
<td>Pulley</td>
</tr>
<tr>
<td>Electric motor</td>
</tr>
<tr>
<td>Take up</td>
</tr>
<tr>
<td>Frame</td>
</tr>
<tr>
<td>Gearbox</td>
</tr>
</tbody>
</table>

All four of the belt conveyors consist of a number of components, each with their own function. In table 2.1, the components of the belt conveyor are listed with their main functions. These functions are the key performance for the operation of the system.
For the application and the scope of the belt conveyor located in the laboratory, the number of components in the scope of the project is limited. The reason for this limitation is the very rare occurrence of a failure or an insignificant small consequence of the failure of these components.

2.1 General belt conveyor components

In the test set-up in the laboratory, four belt conveyors are connected to each other to form one belt conveyor system. These belt conveyors are connected in a loop. All four of the belt conveyors consist of identical parts. So, if the bulk is on the belt conveyor and the system is in process, the bulk will be moved around. This belt conveyor system can be used to test the collaboration of the characteristics of the belt. In order to move the products, all the belt conveyors are working together with each their own function. In the following paragraphs, the components of the belt conveyor are discussed.

Belt

The main function of the belt is to move products from origin to destination. For this movement, the conveyor belt collaborates with other belt conveyor components. The belt is stretched between two pulleys. One of these pulleys is driven by an electric motor. Friction between the belt and the pulley is required to transmit the angular motion into a horizontal motion. The friction between the pulley and the belt depends on the friction coefficients of the surfaces and the tension on the belt. The material of the belt used in the laboratory is rubber.

Prediction of belt damages enhances the belt reliability. The diagnosis and even prognosis on the condition of the belts can be achieved with continuous belt monitoring by using for instance Fuzzy Logic. Corrective actions (i.e. reparation and replacement) can be programmed to prevent a small belt damage from developing into a severe one. This way, according to (Liu, 2016) the belt reliability can be maintained. For the belt monitoring, the technologies can be categorized into non-embedded belt monitoring and embedded belt monitoring according to (Liu, 2016).

The rubber material, which constitutes a significant part of the conveyor belts, is subjected to mechanical, physical and chemical failures (Fedorko et al., 2018). The primary cause of mechanical failures is contact of the conveyor belts cover layers with the material conveyed and with some structural parts of the conveyor belt itself. Physical and chemical failures is the sum of irreversible changes that occur due to the effects of light, heat, sunlight, chemicals and atmosphere. The effects of mechanical, physical and chemical failures usually occur at the same time and the resulting failures of conveyor belts is thus a mutual combination thereof. The failures of conveyor belts are manifested by permanent changes in some of their characteristics, such as thinning of the cover layers, loss of tensibility or loss of strength.

For the mechanical failures of the belt, the most frequent damage and failures of the belt are listed in table 2.2 (Fedorko et al., 2018).
Table 2.2: Most frequent types of belt failures

<table>
<thead>
<tr>
<th>Type of failures</th>
<th>Criticality</th>
<th>Degree to which the failures can be influenced</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Failures of a conveyor belt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abrasion of cover layers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perforation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cracks in cover layer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Damage to the belt rim</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disruption of the belt's structure</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Every type of failure starts at a different position. Some of the failures will be seen over the whole conveyor belt, whilst other failures, for example, might start on the loading area of the belt conveyor only. In table 2.3, an overview is given about the most common locations of mechanical damage to the conveyor belt.

Table 2.3: Origins of mechanical damages on a belt conveyor

<table>
<thead>
<tr>
<th>Place of damage origination</th>
<th>Abrasion of cover layers</th>
<th>Perforation</th>
<th>Cracks in cover layer</th>
<th>Damage to the belt rim</th>
<th>Disruption of the belt's structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hopper/loading area of the CB</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Remaining part of the CB</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Discharging part of the CB</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
</tbody>
</table>

For the set-up in the laboratory, only the non-embedded monitoring technic can be applied because of the belt characteristics. For the embedded belt monitoring, conductors are included in the belt configuration. For the set-up in the laboratory, adjustments on the belt are not allowed according to the design requirements. So only the non-embedded variant is applicable.

Only the mechanical wear is applicable in the laboratory conditions, because there is negligible influence from light, heat, sunlight, chemicals and atmosphere. In the laboratory, there is less sunlight on the belt, because the belt conveyor is located inside a building. The room temperature should not affect the characteristics of the belt and there are no chemicals which can damage the belt condition. This is why the physical and chemical failures are out of scope for the research assignment.

Idler rolls

The main function of the idler rolls is to support the belt with the bulk on it. The idler rolls are positioned into a V-shape to ensure that the bulk stays on the belt along the way. The distance between the idler rolls in longitudinal direction can deviate between different belt conveyor configurations. The number of idler rolls per meter length depends on the mass on the belt. At the beginning, the number of idler rolls per unit length is higher compared to the rest of the belt configuration. The number is higher because of the impact of the bulk which is dispatched from the previous belt conveyor. The wear of the idler rolls depends on the mass of the bulk on the belt. If there is no bulk on the belt, the belt touches the idler rolls just a bit or not at all. So, the rolls are either in rest or rotating without bulk. There will be more friction inside the idler rolls with bulk on the belt compared to the situation without bulk on the belt. This results in much more wear on the idler rolls.

In figure 2.3, the anatomy of the idler roll is shown (Liu, 2016). The shaft shuts in the bearing, the bearing is in contact with the bearing house and on the outside of the idler roll and the shell is in contact with the belt. According (Liu et al., 2018).
the malfunction of the inner bearing is the most common failure mode for the idler roll.

Figure 2.3: Anatomy of an idler roll, (CKIT, 2012). (1) refers to the bearing house. (2) the bearing. (3) the shell. (4) refers to the shaft. (5) represents the sealing system

According to (Liu, 2016), there are three potential approaches to predict idler roll failures: theoretical calculation of the reliability of idler rolls based on their operational conditions (i.e. the load and rotational speed), the detection of idler roll failures based on condition monitoring data, as well as integrated maintenance decision making based on the two previous approaches.

The most common failures on the idler rolls are the malfunction of the inner bearing (Liu, 2019). The idlers are rotating with variant speeds and different amount of bulk. Hence why it is difficult to predict the wear on the bearings.

The focus in this research project is on the sensor selection for the condition monitoring of the belt conveyor components. Therefore, the detection of the idler roll failures based on the condition monitoring data is important for this research project. The experimental study on the condition monitoring of the idler rolls will be determined by different sensors. In the laboratory configuration, the distance between the idler rolls is about one meter. Two of the idler rolls are shown in figure 2.2. The configuration of these idler rolls are in a V-shape.

Figure 2.2: Idler rolls supporting the belt

Pulley
The main function of the pulley is to support and deflect the belting through the conveyor structure (CKIT, 2018). The pulleys are in constant contact with the belt. The tail end pulley is the non driven pulley. At the head of the conveyor, the drive pulley is located. The driven pulley is used to transmit the drive power into the conveyor belt and as such, are subjected to the dynamic belt tension forces in a conveyor. Tension is required to prevent the slip between the belt and the pulley. Slip is a difference in motion between the belt and the pulley and will cause wear on the belt and heat development on the belt and the pulley. The take-up
arrangement can be used to prevent slip. According to (Dakel et al., 2018), two types of slip exists in belt drives: gross and partial slips. The gross slip means a full slip all along the arc length of the contact between the belt and the pulleys. In this case, the belt has a rigid body motion with respect to the pulley and thus the gross slip must be avoided in all the applications. On the other hand, the partial slip is unavoidable in several cases since the friction is needed in order to transmit the power and the motion.

A failure in the bearing of the pulley results in a considerable downtime and cost for reparation or replacement. This is why it is beneficial to monitor the system parameters of the pulley bearing. According to (Van Zyl et al., 2013), another common failure type is the result of fatigue. The cyclic load leading to fatigue failure was caused by the weight of the gearbox and motor being carried (partially) by the conveyor pulley shaft.

A pulley is located both at the beginning and at the end of the belt conveyor configuration in the laboratory. The head pulley is driven by the electric motor. The pulley at the tail end is only for support and deflecting the belt.

**Electric motor**
The function of the electric motor is to drive the belt conveyor system. The electric motor converts electric energy into mechanical energy. The current flowing through a wire coil in a magnetic field creates a force that rotates the coil. The output of the motor is connected to a gearbox. The output shaft of the gearbox is connected to the pulley. According to (Mirza, 2013), the main causes for an electric motor failure are: over-current, low resistance, over heating, dirt, moisture and vibration.

The electric motor used in the belt conveyor system in the laboratory is a Bonfiglioli Synchronous Reluctance Motor. The electric motor is shown in figure 2.4.

![Bonfiglioli electric drive](Image)

**Take-up**
The main function of a take-up arrangement is to ensure the tension on the belt. If the belt stretches out, the take-up arrangement can restore the belt tension to the desirable value by dislocating the pulley. An undesirable amount of tension on the belt can result in slip between belt and pulley or lead to a higher wear on the belt. If the tension on the belt gets too much, it will result in belt breakage. For this
application there are different technics available. The commonly used variants for a take-up arrangement are:

- **Gravitational take-up**

  ![Figure 2.5: Schematic overview of a gravitational take-up arrangement](image)

  The mass (e) gives a gravitational force on the pulley (d). The gravitational force on the pulley will result in a constant tension on the belt depending on the mass. If the belt is stretching out, the tension on the belt is constant, because the gravitational force on the mass is constant.

- **Winch take-up**

  ![Figure 2.6: Winch take-up unit (Saimh, 2018)](image)

  The winch shown in figure 2.6, is located at the end of the system and is connected to the axis of one of the pulleys. With an adjustable location of the pulley, the tension on the belt can be differentiated by setting the tension on the winch. The advantage of this system is the ease of differentiating the tension on the belt by using the winch.

- **Screw take-up**

  ![Figure 2.7: Screw take-up system used in the laboratory configuration](image)

  The third option is the screw variant which is used in the laboratory. It is possible to change the position of the pulley by a screw on both shaft ends. By a dislocation
of the pulley axis in horizontal direction, the tension on the belt can be differentiated.

Frame
The function of the conveyor frame is to support the connected components to deal with static and dynamic loads. The frame of the belt conveyor should resist the loads on the belt conveyor. The loads on the frame are caused by the tension on the belt, loads on the belt and the weight of the frame added with the connected components. The screw take-up causes a tension in the belt that needs to be compensated by the frame. Additionally, gravitational force of the bulk on the belt should be compensated by the frame. The vibrations in the frame are caused by the rotational parts and possibly by external influences. For vibrations response measurement multiple vibrations acceleration and velocity sensors were fixed in different positions of the tension rod, measuring in different directions (Klinger, 2014). The interesting parameters of the frame will be the tension and the vibrations in the frame.

The weight of the bulk on the belt is low and the set-up is relatively small compared to other belt conveyor configuration. These construction calculations can be done by different programs, for example FEMAP. This is not the main focus of this research project. Because the robust frame the negligible external influences according to the favourable laboratorial conditions, the sensor selection for the frame is out of scope for the research project. Because the frame is out of scope, the frame parameter will not be included in the sensor selection.

Gearbox
The main function of the gearbox is to increase the torque on the pulley axis by transitioning the speed of the drive axis. For the application of the belt conveyor systems, in-line helical gear boxes, worm boxes, and bevel-helical are used to power these systems. The common cause of a failure in the gearbox are the lubricant, alignment of gears and the overload (Foti, 2012).

The variant of the bevel-helical gearbox is used in the laboratory. The sensor selection for preventing the failures in the gearbox is out of scope, because the gearbox is not one of the particular system components according to (Górniak-Zimroz et al., 2009).

2.2 Laboratory conveyor system

The scope of this research project will be limited to the particular system components of the belt conveyor located in the laboratory (Górniak-Zimroz et al., 2009). Not all of the system components are considered into the sensor selection for a monitoring system, because of negligible failure rate or the small potential consequences in case of a failure. According to (Liu, 2016), the reliability of the belt conveyor system is dependent from the reliability of the components. The four components included in this study to determine the system reliability are: the belt, drive unit, pulleys and idlers. Also according to (Górniak-Zimroz et al., 2009), the particular system components of a belt conveyor system are: the belt, the idlers, the
pulleys and the electric motor. Most of the failures will occur in these parts. The result will be a sensor selection to measure the significant component parameters. The take-up, frame and gearbox are out of scope of the monitoring system, because these components are not one of the key components for the conveyor maintenance management (Górniak-Zimroz et al., 2009).

Take all together, the scope of the research project is limited to the following conveyor components: the belt, idler rolls, pulleys and an electric motor. The components within the scope of the project, are listed in table 2.4 with their main functions. Later this in the report, the system parameters will be defined for a sensor selection of the belt conveyor located in the laboratory.

Table 2.4: Components into the scope of the monitoring system with their main functions.

<table>
<thead>
<tr>
<th>Components into the scope of the project</th>
<th>Belt</th>
<th>Idler</th>
<th>Pulley</th>
<th>Electric motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>function</td>
<td>move products</td>
<td>support belt</td>
<td>support movement outline shaft</td>
<td>drive</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>change belt direction</td>
<td></td>
</tr>
</tbody>
</table>
3. Component parameters for a monitoring system

Monitoring objectives
Analysing the main components by a monitoring system will produce data from the parameters of the belt conveyor. The obtained data from the monitoring objectives are used for a more informed decision about the maintenance strategy of the belt conveyor system. This more informed decision will lead to a better maintenance efficiency of the belt conveyor system.

The main functions of each component of the belt conveyor system have been discussed in the previous chapter. Each component has different parameters that should be interesting for the operational or technical conditions of the components. For each component, the parameters are listed in a table 3.5 with a distinction if the parameter is important for the technical or the operational condition of the system.

Technical conditions
The technical condition is about the health of the components of the belt conveyor system (Pang et al., 2010). The technical condition of these components can be monitored by multiple sensors. The output of these sensors can be used for the evaluation of the health of the system components.

Operational conditions
A belt conveyor component is in operational condition when it properly performs its required functions (The Gale Group, 2010). To monitor if a component performs in this condition, some parameters can be measured by different sensor types. The component parameters given in this chapter belong to the operational or technical conditions of the system components.

3.1 Belt parameters

The measurable parameters of the belt are discussed in the next paragraphs. For the monitoring system in the laboratory, not all of these parameters are significant. Some of the parameters should be interesting, but are not possible to measure for the test set-up in the laboratory. Other parameters could be interesting for industrial application, but must deviate from the laboratory conditions. This research project is focused on the test set-up in the laboratory which means that the parameters on the belt should be applicable in the laboratory conditions.

Alignment
The alignment of the belt is an important parameter for the belt for the monitoring of the transverse position of the belt. Misalignment can cause edge damage when the belt rubs against structure, boot ends or may even be folded over in splicing tables and loops (Owen, 1997). Damaged edges can result in bulk spillage or a restricted amount of bulk on the belt.
Speed
For the operational condition of the belt, it is essential to measure the speed of the belt combined with the bulk on the belt. These two parameters will result in an amount of bulk transported per unit of time. The speed of the belt can be compared with the speed of the pulley. This comparison will result in the amount of slip between the belt and the pulley. Minimization of the amount of slip will be desirable. The speed parameter of the belt is both an operational parameter as a technical parameter.

Tension
The tension on the belt is supposed to be an important parameter (Liu et al., 2015). Too little tension on the belt might cause slip between the pulley and the belt. The result of slip is energy loss and an increased amount of wear on the belt. The take-up used in the laboratory is the screw take-up. The take-up arrangement provides the amount of tension on the belt. So, the tension in the belt is an important parameter to monitor for a better overview of the belt characteristics. The tension on the belt is a parameter about the technical condition of the belt. With this information, belt slip and wear can be minimized.

Monitoring belt parameters
The significant belt parameters for the operational and the technical condition of the belt are given in table 3.1.

**Table 3.1: Belt parameters**

<table>
<thead>
<tr>
<th>Components</th>
<th>Belt</th>
<th>Operational</th>
<th>Technical</th>
</tr>
</thead>
<tbody>
<tr>
<td>function</td>
<td>move products</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parameter</td>
<td>misalignment</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>speed</td>
<td>+</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>tension</td>
<td>-</td>
<td>+</td>
<td></td>
</tr>
</tbody>
</table>

3.2 Idler rolls parameters

For the idler rolls, the most common failure is the malfunction of the inner bearings (Liu et al., 2018). In this section, the main goal is to investigate which parameters are significant for the malfunction of the inner bearing of the idler rolls.

Temperature
A clear view about the technical conditions or ‘technical health’ of the bearing in an idler roll can be given by measuring its temperature. According to (Lodewijks et al., 2007), the normal operating temperature ranges between 20 °C and 50 °C depending among others on the ambient temperature. If the temperature of a bearing increases, ranging from 80 °C to 120 °C, it is a clear sign of potential bearing failure. For the laboratory configuration of the belt conveyor, the ambient temperature is room temperature. This is why it should be possible to measure the difference in temperature of the bearing in case of failure in the laboratory conditions. For
outdoor conveyor sections, the temperature varies widely based on ambient conditions, making it a poor indicator of machinery health (Schools, 2015).

Acoustic emission
Acoustic sensors can be interesting for the condition monitoring of the idler rolls. In case of an abnormal sound production of the idler rolls, the condition of the idler rolls is affected. According to (Liu, 2016), the acoustic emission of idler rolls in the final failure stage shows some distinct differences from intact idler rolls. This technic should be interesting to measure and monitor the sound of the idler rolls during motion because the ambient sound level is very low in the laboratory area. It is harder to measure the acoustic emission in industrial conditions because of the ambient noise. Each situation is different but it can be studied under laboratory conditions.

Vibration
The vibration in the idler rolls can be caused by multiple motions of other components. In an ideal configuration, there is no vibration in the idler rolls and the bearings. A vibration in the idler roll means an oscillation about an equilibrium point. Vibration should be an interesting parameter for the research of the condition of the idler rolls. According to (Bartelmus et al., 2000), investigations have shown a relation between design features of an idler roll and a vibration spectrum generated by the idler during its rotation. It may be stated that the vibration spectrum of the idler rolls is a measure of the idler roll quality. During rotation of the idler rolls two types of vibration spectrum components are generated. These components are rotation dependent and rotation independent. Therefore, vibration will be studied in both the overall and laboratory condition.

Monitoring idler rolls parameters
In table 3.2, the monitoring idler roll parameters are given. The parameters are divided into operational and technical parameters.

<table>
<thead>
<tr>
<th>Components</th>
<th>Idler</th>
<th>Operational</th>
<th>Technical</th>
</tr>
</thead>
<tbody>
<tr>
<td>function</td>
<td>support belt</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>parameter</td>
<td>temperature</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>acoustic emission</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>vibration</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

3.3 Pulley parameters
The most common failures of the pulley are a result of the bearing failure or a result of the fatigue (Liu, 2016). The conditions of the pulley bearings are monitored by the temperature and the vibrations in the bearings. The rotating speed of the pulley is an important parameter to compare with the speed of the belt. According to these units of speed, the amount of slip between the pulley and the belt can be determined.
Temperature
The temperature in the bearing is a suitable method to detect a bearing failure in an early stage. According to (Owen, 1997), when the bearing temperature exceeds the seventy degrees Celsius, grease begins to thin and may run out. If the bearing reaches ninety degrees Celsius, then imminent failure is likely. The ambient temperature is regulated as room temperature in the laboratory condition. This is why the measurement of the temperature is a suitable option in laboratory condition.

Vibration
According to (Owen, 1997), a vibration analysis requires more sophisticated equipment as it is only certain frequencies that depict problems with a bearing. However, any excessive vibration detected by accelerometers will provide some early protection. The method to measure the vibration in the pulley bearing in the laboratory condition is a suitable solution. Additionally, for the overall condition, the vibration should be measured to determine the system characteristics. The vibration of the shaft should not be affected by the surroundings.

Rotating speed
The pulley is driven by the electromotor. The rotational speed of the pulley will result in the speed of the belt. Slip is the difference between the motion in the pulley and the belt speed. To monitor this amount of slip, both of the belt speed and the rotating speed of the pulley are required.

Monitoring pulley parameters
For monitoring the condition of the pulley, the temperature, vibration and the rotating speed of the pulley are the significant parameters. These parameters can give more information about operational or technical condition of the pulley. The fatigue of the pulley shaft is neglected, so the stress and the number of cycles of the pulley are the non-interesting parameters for the monitoring system. The significant parameters of the pulley are listed in table 3.3.

<table>
<thead>
<tr>
<th>Components function</th>
<th>Pulley</th>
<th>Operational</th>
<th>Technical</th>
</tr>
</thead>
<tbody>
<tr>
<td>temperature</td>
<td>-</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>vibration</td>
<td>-</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>rotating speed</td>
<td>+</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

Table 3.3: Significant pulley parameters
3.4 Electric motor parameters

Power
The power generated in the electric drive is important to drive the system. Power in the drive can be calculated by multiplying the current and the voltage, given in formula 3.1:

\[ P = U \times I \]  

(3.1)

\( P \) = Power [kW]
\( I \) = Current [A]
\( U \) = Voltage [V]

The multiplication can be performed by electronic circuit that is usually digital and that can be incorporated in a watt transducer. It is often done by the computer for DAC that allows voltage and current as well the computer-derived power to be displayed (Pang et al., 2010).

Another option to calculate the power of the electromotor is by using formula 3.2:

\[ P = \frac{T \times v}{r} \]  

(3.2)

\( P \) = Power [kW]
\( T \) = Torque [Nm]
\( v \) = Belt speed [ms\(^{-1}\)]
\( r \) = radius of pulley [m]

The output power depends on the current and the voltage. For the technical state of the drive unit, the efficiency of the drive will be determined by formula 3.3:

\[ \eta = \frac{P_{out}}{P_{in}} \times 100\% \]  

(3.3)

In figure 3.4, the overview of the electric motor is given.

Table 3.4: Significant electric motor parameters

<table>
<thead>
<tr>
<th>Components</th>
<th>Electric motor</th>
<th>Operational</th>
<th>Technical</th>
</tr>
</thead>
<tbody>
<tr>
<td>function</td>
<td>Drive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>parameter</td>
<td>power</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>
3.5 Parameter selection

In table 3.5, the components of the belt conveyor are listed with their main function, common failures, and parameters. The significant parameters for the system will be measured by sensors. The applicable sensors to measure these parameters will be discussed in chapter 4.

Table 3.5: Final selection of the system components in to the scope of the project and parameters under technical or operational conditions, (O = operational parameter, T = technical parameter)
4. Sensor selection

Which parameters are significant to include in the sensor selection for the test set-up located in the laboratory is shown in chapter 3. But for each component there are various ways to measure these parameters. In this chapter, the applicable and available sensors will be discussed for each selected parameters of the belt conveyor system. For the consideration of the selected sensors, there are some design requirements mentioned in chapter 1. The selection of the sensors in this chapter should comply with the design requirements.

4.1 Belt sensors

According to chapter 3, the significant parameters for the sensor selection of the belt conveyor configuration in the laboratory are: the misalignment, speed and tension on the belt. The sensors used for the monitoring system are chosen according to the design requirements per parameter.

Misalignment

The alignment switch is used for the monitoring of the misalignment of the belt. Belt alignment switches are traditionally applied to monitor the transverse position of the belt (Figure 4.1). Because of the design requirements, the embedded magnet variant cannot be implemented.

Alignment switch

Misalignment will result in damage to the belt, rollers and the spillage of the conveyed material. Generally, an alignment switch is used in a pair of on/off switches, one on each side of the belt to be protected at points where belt misalignment is likely to occur. The unit is activated when misalignment of the belt exceeds a certain extent and thus the conveyor can be stopped before the belt or the associated rollers are damaged.

For the alignment of the belt, the MBA2A mechanical alignment sensor is used. More information about the alignment switch is given in Appendix A1.

Figure 4.1: Alignment switch (4B Braime Group, 2018)
The speed of the belt can be measured by multiple sensors. There are no magnets embedded into the belt surface. According to the design requirements, the magnet implementation into the belt surface is not possible, so the method used for the measurement of the belt speed on the test set-up is a contact sensor. A few belt speed sensors are listed:

- Siemens RBSS Speed sensor
- Siemens TASS speed sensor
- Siemens Sietrans WS300 speed sensor
- Tecweigh SS60 speed sensor
- ELM-2000 Digital Surface Speed Meter

<table>
<thead>
<tr>
<th>Siemens RBSS Speed sensor</th>
<th>Siemens TASS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution: 60 pulse/revolution</td>
<td>Resolution: 5 pulse/revolution</td>
</tr>
<tr>
<td>1711210 (Instrowest, 2019)</td>
<td>1711211 (Instrowest, 2019)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Siemens Sietrans WS300</th>
<th>Tecweigh SS60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution: 256 pulse/revolution</td>
<td>Resolution: N/A</td>
</tr>
<tr>
<td>1711212 (Instrowest, 2019)</td>
<td>1711305 (Instrowest, 2019)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ELM-2000 Digital Surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max speed: 2000 f/m = 10m/s</td>
</tr>
<tr>
<td>(hoto-instruments, 2019)</td>
</tr>
</tbody>
</table>

The simple installation of the Siemens Sietrans WS300 and the ELM-2000 Digital Surface are not sufficient according to the design requirements. The Siemens Sietrans WS300 is a sensor for the axial rotation and should therefore be adjusted. The consideration is between the return belt speed sensors RBSS, TASS and SS60.
For the belt configuration in the laboratory, the Siemens RBSS speed sensor is chosen, because of the extremely accurate speed detection (Appendix A2). The Siemens RBSS meets the design requirements set for the sensor selection.

**Tension**
The tension in the belt is required to prevent slip between the belt and the pulley. Load cells are applied in the belt conveyor monitoring for example to monitor the belt tension (Pang et al., 2010).

**Load cell**
Load cells are transducers that produce an electrical signal when subjected to a force and are commonly used in laboratory instruments to measure static and dynamic forces (Maranzano et al., 2016). For the measurement of the tension in the belt, a load cell is a suitable option. The various loads cell types include hydraulic, pneumatic or strain gauge. In force measurement, strain gauge force sensors are the most commonly used type of force transducer, to the extent that, the term “load cell” usually implies this type of sensors (Pang et al., 2010). The strain gauge is the most commonly used devices for strain measurement according to (Pang et al., 2010), which have been in use for many years as the fundamental sensing element for measuring force, tension and torque.

The strain in a component is the deformation in the length direction divided by the original length due to the force applied by the take-up. The mechanical part in shown in figure 4.2, is the screw connection of the take-up. The tension in the belt is equal to the tension in this screw. Because the belt is in motion, it is more complicated to measure the tension in the belt. For the stress in the part, the strain is required and can be calculated by formula 4.1:

\[
\varepsilon = \frac{\Delta L}{L}
\]  

(4.1)

![Figure 4.2: Elongation of a mechanical part](image)

The stress (\(\sigma\)) can be calculated by the strain multiplied by the Youngs’s Modulus (formula 4.1). The Young’s Modulus depends on the used material of the mechanical part in the laboratory configuration.

\[
\sigma = G\varepsilon
\]  

(4.2)
The load cell is used to monitor the tension in a take-up. According to the design requirements, the Thru-hole or donut load cells are used for the measurement of the tension in the take-up. An other option for the measurement of the tension is the S-shape load cell, but it is not allowed to adjust the system components, so these variant is no possibility for the research assignment.

LTH series load cell (figure 4.4) is used in the laboratory configuration. More information about the LTH series is given in Appendix A3.

![Figure 4.4: LTH series](image)

4.2 Idler sensors

The common failure in the idler rolls are in the bearing of the idlers. According to chapter 3, the main parameters for indicating this failure are the temperature, acoustic emission and the vibration in the bearing. In this paragraph, the sensors used for the monitoring system of the idler parameters are discussed.

**Temperature**

According to (Ametherm, 2018), there are four types of sensors available for the temperature monitoring.

1. **Negative Temperature Coefficient (NTC) thermistor**

   The working principle of the negative temperature coefficient thermistor is a resistor with a very high resistance at low temperatures and a low resistance at high temperatures. Small temperature changes are very reflected very fast with a high accuracy (0,05 to 1,5 °C). The range for the NTC is between -50 to 250 °C.

2. **Resistance Temperature Detector (RTD)**

   A resistance temperature detector is a resistance thermometer. The temperature is measured by correlating the resistance of the RTD. The range of the temperature is about the -200 to 600 °C. While providing the greatest accuracy, RTDs also tend to be the most expensive of temperature sensors.
3. Thermocouple
A thermocouple sensor measures the temperature by the different between to voltages in wires connected at two different points. The accuracy is not very high (0.5 °C to 5 °C) and the temperature range is the widest compared to the other variants (-200 °C to 1750 °C).

4. Semiconductor-based sensors
The semiconductor-based sensors are two identical diodes that can monitor the changes in temperature by temperature sensitive voltage and current characteristics. The advantage of the semiconductor compared to the other variants is the slowest response time (5 to 60 s). Besides the response time, the temperature range is between -70 to 150 °C, the smallest range of the four temperature variants.

The last variant of the temperature monitoring is the infrared camera.

5. Infrared camera
The infrared camera uses the electromagnetic spectrum. All objects emit an amount of radiation as a function of the object temperature. The accuracy of the infrared camera is 2 °C and the resolution 80x60 pixels. The range of the FLIR AX8 infrared camera (Lodewijks et al., 2007) is between -10 to 150 °C. This range is suitable for the idler bearings in the laboratory set-up. The infrared camera is given in figure 4.5.

In the test set-up of the belt conveyor system in the laboratory, the temperature in the bearings of all the idler rolls can be detect by the infrared camera. The infrared camera is a non-contact sensor. The infrared camera is chosen because of the ease of installation compared to the thermocouple.

**Acoustic emission**
Acoustic sensors are also applied to assist idler roll inspection. For instance, (SKF, 2012) has developed the idler sound monitoring kit to assist conveyor inspectors to spot idler rolls which generates an abnormal sound (Pang et al., 2010). For the application of the monitoring of the acoustic emission of the bearings, there are three variants available:

- Omni-directional microphone
- Uni-directional microphone
• Sound level meter

The uni-directional microphone is used because of the ambient noise. This sensor is capable to monitor the acoustic emission from the pointed direction. The omni-directional microphone is more subjected to environmental noise. There is a possibility of environmental noise in the laboratory condition, so the uni-directional microphone is a more suitable option. In addition, the following uni-directional microphone is used for the frequency monitoring: CEM-OB6022-EJAD443P1.9R (Appendix A4) with (range (Hz): 50-200, sensitivity (dB): -44±3).

Vibration

There are two types of accelerometers available for the monitoring of the vibrations of the bearing. The two-axis variant and the three-axis variant (Dimension Engineering, 2019).

The DE-ACCM6G is an off-the-shelf 2 axis 6g accelerometer solution with analogue outputs. It features integrated op amp buffers for direct connection to a microcontroller's analogue inputs, or for driving heavier loads (figure 4.3a).

The DE-ACCM3D is the most advanced analogue accelerometer solution to date, featuring a triple axis ±3g accelerometer chip. It also has integrated op amp buffers for direct connection to a microcontroller's analogue inputs, or for driving heavier loads (figure 4.3b).

The three-axis DE-ACCM3D is the best option for the vibration in three directions. For disadvantage is the higher cost price compared to the two-axis variant. More information about the DE-ACCM3D accelerometer is given in Appendix A5.

Vibration sensors are of the accelerometer type, with a typical output of 100 mV/g of acceleration. Temperature sensors are generally RTDs, either built into the accelerometer or external. Both sensor types are usually hardwired back to the condition monitoring system inputs (Schools, 2015).

4.3 Pulley sensors

The temperature, vibration and the rotating speed are the significant parameters for the monitoring system of the pulley parameters, according to chapter 3. The temperature and the vibration are important parameters for the system characteristics of the pulley bearing. The rotating speed is required to monitor the slip between the belt and the pulley. Slip is a loss of energy and an increasing amount of wear on the belt.

Temperature

The temperature in the bearing is an important parameter for the condition monitoring of the pulley bearing. The sensor for the temperature in the idler roll bearings are discussed in paragraph 4.2. The same sensor type should be interesting for the temperature monitoring of the pulley, because of the design requirement of
the use of equal sensors. So, the infrared camera measures the temperature distribution in the pulley bearing.

**Vibration**
Excessive vibration detected by accelerometers will provide some early protection. This is why the accelerometer is used for the detection of vibration in the pulley axis. The vibration in the pulley axis will lead to pulley bearing failures. The accelerometer to detect the vibration in the idler bearing are discussed in paragraph 4.2. In each pulley bearing the vibrations will be monitored with a three-axis accelerometer. The accelerometer DE-ACCM3D will be applied in all the pulley bearings. Four sensors are needed to equip each bearing with these sensors.

**Rotational speed**
The rotating speed can be compared to the belt speed to detect the slip between the belt and the pulley. If there is no slip, the speed of the belt should be equal to the speed of the outer surface of the pulley. According to the design requirements, identical sensors should be applied for the measurement of the same parameter. This is why the Siemens RBSS sensor (Appendix A2) is selected to measure the speed of the pulley. In figure 4.6, the Siemens RBSS Speed meter is given.

![Figure 4.6: Siemens RBSS Speed sensor](https://instrowest.com.au/siemens-rbss-speed-sensor.html)

**Resolution:** 60 pulse/revolution

**4.4 Electric motor sensor**

For the operational condition of the belt conveyor system the power output of the electric drive is the main parameter. For this parameter a power meter is used for the output power of the electric motor. The power is measured in Watt.

**Power**
The direct means of monitoring power is to use watt transducers (Pang et al., 2010). The electrical power is equal to the product of voltage and current multiplied by the power factor. The multiplication can be performed by electronic circuitry that is usually digital and that can be incorporated in a watt transducer. It is often done by
the computer for DAC that allows voltage and current as well the computer-derived power to be displayed (Pang et al., 2010).

4.5 Enumeration of the chosen sensors

The sensor types chosen for the parameter monitoring of the belt conveyor components are given in table 4.1. These sensors are used in chapter 5 for the configuration of the sensor on belt conveyor system. These sensors will give more information about the technical and operational conditions of the belt conveyor system located in the laboratory.

Table 4.1: Enumeration of the used sensors for the monitoring system

<table>
<thead>
<tr>
<th>Belt</th>
<th>Idler</th>
<th>Pulley</th>
<th>Electric motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>misalignment</td>
<td>alignment switch</td>
<td>temperature</td>
<td>FUR AX8</td>
</tr>
<tr>
<td>speed</td>
<td>Siemens RBSS</td>
<td>acoustic emission</td>
<td>uni-directional microphone</td>
</tr>
<tr>
<td>tension</td>
<td>LTH Series</td>
<td>vibration</td>
<td>DE-ACCM3D</td>
</tr>
<tr>
<td></td>
<td></td>
<td>temperature</td>
<td>FUR AX8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>vibration</td>
<td>DE-ACCM3D</td>
</tr>
<tr>
<td></td>
<td></td>
<td>rotating speed</td>
<td>Siemens RBSS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>power</td>
<td>power meter</td>
</tr>
</tbody>
</table>
5. Location of the selected sensors

The location of the sensors selected in chapter 4 are discussed in this chapter. In this chapter the determination of the location for each sensor is given. The sensors located on the belt conveyor are applied on each of the four belt conveyors to give the information about the technical and operational conditions of the belt conveyor system.

5.1 Belt sensors

The alignment switches are used in the beginning and at the end of the belt close to the location of the pulleys. The alignment switch is used on a position where the belt misalignment is likely to occur. The alignment switches are used in pairs of on/off switches. The position of the alignment switches (A) is given in figure 5.1. For the location of the RBSS speed sensor, an as small as possible vibration on the belt is preferred. The speed sensor should be constant in contact without vibrations on the belt for an optimal speed measurement. The belt is strained between the two pulleys, so the optimal location for the speed sensor is close to the pulley (B).

The load cells are located on the screw of the take-up. The tension on the belt is equal to the tension on both of the screw connections of the take-up. The load cell should be installed on both of the pulley sides to compared the load of both sides. These two load should be equal to prevent the system for misalignment. Two load cells are required per belt conveyor, in total eight. The location of the load cell is given in figure 5.2.
5.2 Idler roll sensors

Six infrared camera should be installed towards the shaft ends with negligible distance (Liu, 2016). The camera should be installed on each of the idler rolls to give information about the bearing temperature and so on the technical condition of bearings in the idler rolls. The camera should be installed on both sides of the idler rolls because there are two bearings in each of the idler rolls. The location of the infrared sensors are given in figure 5.3A.

The acoustic emission of the idler roll is monitored by a microphone. The location of the sensor is 50 cm from the source of the sound produced sound by the bearing. The location of the microphone is given in figure 5.3B.
In figure 5.4, the location of the accelerometer is given to detect the vibrations in the idler rolls. The accelerometer is placed on each idler bearing.

![Figure 5.4: Location of the accelerometer.](image)

### 5.3 Pulley sensors

There are three sensors for the bearing on the pulley shaft. The bearing of the pulley is monitored on the vibration and the temperature. The speed of the pulley is measured by a return speed meter. An infrared camera should be installed to measure the temperature of in the bearing of the pulley. The location of these infrared camera is close to the bearing, given in figure 5.5.B. For each pulley, two infrared cameras are required. In figure 5.5A, the location of the speed meter is given. The sensor is located on this side of the pulley because the sensor cannot touch the belt in cause of misaligning of the belt. In figure 5.6 the location of the accelerometer is given to detect the vibrations in the pulley shaft and so on in the bearing.

![Figure 5.5: Configuration of the pulley sensors](image)
Figure 5.6: Location of the accelerometer
6. Conclusion and recommendation

6.1 Conclusion

A belt conveyor system is commonly used for the transport of products from origin to destination. A belt conveyor system is located at the Delft University of Technology. The goal of this research assignment is the sensor selection to increase the reliability for the belt conveyor system in the laboratory. The main reason for a sensor selection is to give more information about the system parameters.

The belt conveyor system located in the laboratory contains a number of components. Not all of the system components are significant for a monitoring system because of negligible failure rate or the small potential consequences in case of a failure. The scope of the research project is limited to the following system components: the belt, idler rolls and pulleys. The reliability of the belt conveyor system depends on the reliability of the components.

Each main component of the belt conveyor system consists of various system parameters. The parameters are divided into technical and operational parameters. The technical condition is about the health of the components of the belt conveyor system. A belt conveyor component is in operational condition when it properly performs its required functions. The sensors are selected to give more information about the technical or operational condition of the components. The misalignment, speed and tension are the monitored parameters of belt. For the idler rolls, the temperature, acoustic emission and vibrations in the bearing are the main parameters. In the bearing of the pulley, the temperature, vibration and acoustic emission are monitored. For the electric drive of the system, the power output is the main parameter.

Various sensor types are required for monitoring the component parameters. Different sensors are available for each application. An alignment switch, belt speed meter and a load cell are the sensors required to measure the belt parameters. The temperature in the idler roll bearings are measured by an infrared camera. An unidirectional microphone is used for the acoustic emission of the idler roll bearing. The accelerometer is used to detect the vibrations in the bearing. For the pulley parameters, an infrared camera is used for the pulley bearing. An accelerometer is used to measure the vibration in the pulley shaft. And last but not least, a tachometer is used for the rotating speed of the pulley.

To obtain information on the main components, all these sensors are located on the four belt conveyors located in the laboratory. By implementing these chosen sensors, the first step is taken for a real-time monitoring system of the system parameters. Subsequently, the system parameters can be introduced and integrated into a software program. This configuration will be a step up for the development of a diagnostic system. The sensor will give a value of each measured parameter in the sensor selection. In case of a component failure, the system operator needs to come in action for maintenance or replacement activities (figure 5.5 b).
6.2 Recommendations

- The sensor selection as described, can be converted into an autonomously functioning instrument. This can be realized by the development of an expert system. An expert system like such can be realized by the development of a prediction system of the occurrence of the operational failures.

![Diagram a)

Figure 5.5: Design of an expert control system(a) and a decision support system for belt conveyor transport(b) (D. Mazurkiewicz, 2015)

- Historical component data can be analyzed and enable us to make a safety diagnostic system of the transport belt. The measured value can be combined with the predicted value from the historical component data.

The measured value can be compared to the historical data and will give an output. The value of this diagnostic system might be further increased by a suitable expert system that predicts values of analyzed time series and prevents falls alarms signals including the algorithms used in such expert system (figure 5.5.C).

![Diagram b)

Figure 5.5 c: Intelligent advisory system for the monitoring of belt joints

In this way, the system operator does not take decisions on its own, the autonomously monitoring system as described above will prevent unjustified stoppages of the transport system, unnecessary inspections of the joint and complicated and time-consuming examinations of the transport belt.

- Connect the monitoring system to a digital twin. This digital twin will give continues information about the system parameter, the maintenance history and the usage of the belt conveyor system.
Bibliography


Appendices

Appendix A1: Alignment switch

Conveyor Belt Alignment & Rip Detection System

APPLICATION
The Bulldog alignment and rip detection switch is an electro-mechanical system designed to detect dangerous misalignment of the conveyor and also detection of belt tear damage.

METHOD OF OPERATION
The switch will detect horizontal misalignment of belts when contact is made with the roller, the roller arm will be forced to pivot by the belt activating a switch at 20° to trigger an alarm, and 35° to trigger a shut down procedure of the conveyor. The sensors are usually installed in pairs on opposite sides of the belt.

A steel flexible wire is set below the running conveyor belt approximately 20-30mm attached by a rare earth magnet at each end. If the belt is ripped or damaged the wire is pulled away releasing the magnet connection which in turn will activate a switch.

FEATURES
- ATEX Zone 21 Approved
- Easy installation
- No calibration required
- Robust design
- 20° Alarm output
- 35° Stop output

PART NUMBERS
- MBA2A - Mechanical Belt Alignment
- MBA2RA - Mechanical Belt Alignment with belt rip
- MBR2A - Mechanical Belt Rip

Detailed specification, wiring diagrams and installation/operating instructions available immediately upon request.

www.go4b.com
## TECHNICAL SPECIFICATIONS

<table>
<thead>
<tr>
<th>TYPE</th>
<th>MBA2A, MBR2A, MBAR2A</th>
</tr>
</thead>
<tbody>
<tr>
<td>APPROVALS</td>
<td>ATEX ZONE 21</td>
</tr>
<tr>
<td>SUPPLY</td>
<td>12-24VDC and 110-240VAC</td>
</tr>
<tr>
<td>RATING</td>
<td>5 Amps (must be fused externally)</td>
</tr>
<tr>
<td>CONTACT ALARM</td>
<td>ALARM: 1 Contact NO; 6 Amps; 240VAC (non inductive)</td>
</tr>
<tr>
<td>CONTACT STOP</td>
<td>STOP: 1 Contact NO; 6 Amps; 240VAC (non inductive)</td>
</tr>
<tr>
<td>DIMENSIONS</td>
<td>Height x Length x Width</td>
</tr>
<tr>
<td></td>
<td>88mm x 314mm x 113mm</td>
</tr>
<tr>
<td>CABLE ENTRY</td>
<td>1 x M25</td>
</tr>
<tr>
<td>WEIGHT</td>
<td>1.2Kg</td>
</tr>
</tbody>
</table>

---

**Accessories**

- TSOO HOTBUS Site-wide monitoring System
- WDC1 – Watchdog Super Elite
- CBS2VCA – Control unit 110 / 240vac
- MBA2BR – Stainless steel rollers
- BUR – Belt Rip adjustable Wire rope with magnets & 1 bolts

Detailed specification, wiring diagrams and installation/operating instructions available immediately upon request.
Appendix A2: Speed sensor

Milltronics RBSS is a high resolution, wheel-driven return belt speed sensor.

Benefits

- Rugged design
- IP67 rated
- Easy, low cost installation
- Accurate belt speed detection

Application

Milltronics RBSS monitors conveyor belt speed, with the output signal transmitted by cable connection to the integrator (Milltronics BW500, or SIWAREX FTC).

Easily installed close to the belt scale assembly, the RBSS provides a signal generated as the wheel on the sensor rotates on the return belt. To secure this cost-effective unit in place, position a cross bar between stringers - either just before or after a return belt idler, or use the optional mounting bracket. The weight of the RBSS ensures positive rotation of the wheel in the middle of the return belt, and pulses from the magnetic sensor are generated by the rotation of the 60 toothed speed sprocket driven by the wheel. The RBSS output can be applied to any Milltronics belt scale integrator.

Design

<table>
<thead>
<tr>
<th>RBSS Standard Mounting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pin clip</td>
</tr>
<tr>
<td>24 (1) washers, 2 places (customer supplied)</td>
</tr>
<tr>
<td>Stringer</td>
</tr>
<tr>
<td>Cable</td>
</tr>
<tr>
<td>Wheel</td>
</tr>
<tr>
<td>Return belt</td>
</tr>
<tr>
<td>Stringer</td>
</tr>
<tr>
<td>24 (1) dia. cross bar</td>
</tr>
<tr>
<td>(customer supplied)</td>
</tr>
</tbody>
</table>

RBSS installation, dimensions in mm (inch)
Appendix A3: Load cell
PRODUCT INFORMATION

PART # CEM-OB6022-EJAD443P1.9R Revision: 1-2013

Omni Directional Back Electret Condenser Microphone

DESCRIPTION
Challenge Electronics Omni Directional Back Electret Condenser Microphone with a FET, 6.0 mm diameter and 2.2 mm high, PCB version E, JA ≤ 10 V max Power Supply, -44 ± 3 dB sensitivity, D = 2.2 K Hz External Loading Resistance, Pins termination, 1.9 mm Spacing, RoHS Lead Free Compliant.

FEATURES
- RoHS, Lead Free Compliant
- Green Product

SPECIFICATIONS

<table>
<thead>
<tr>
<th>Direction</th>
<th>Omni Directional Back Electret</th>
<th>Compliance</th>
<th>RoHS Lead Free</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Voltage Range</td>
<td>1.0 Vdc to 10.0 Vdc</td>
<td>Power Supply (Vs)</td>
<td>2.0 V</td>
</tr>
<tr>
<td>Frequency Range</td>
<td>50 to 20,000 Hz</td>
<td>Maximum Current</td>
<td>0.5 mA</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>-44.0 ± 3.0, (0 dB = 1V / Pa) at 1K Hz</td>
<td>Minimum Signal to Noise Ratio</td>
<td>58</td>
</tr>
<tr>
<td>Sensitivity Reduction</td>
<td>3.0 V to 2.0 V Maximum -3 dB</td>
<td>Maximum input S.P.L.</td>
<td>110 dB at 1.0 KHz, THD &lt;1%</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>-30°C to +60°C</td>
<td>Storage Temperature</td>
<td>-40°C to +75°C</td>
</tr>
<tr>
<td>Loading Resistance (RL)</td>
<td>External, 2.2 K Ohms, Vs =2.0 V</td>
<td>Built in Capacitors</td>
<td>None</td>
</tr>
<tr>
<td>Dimensions</td>
<td>Pins, 0.45 mm Diameter, 2.5 mm Long, 1.9 mm Spacing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Housing Material</td>
<td>Aluminum / Magnesium Alloy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCB Version Style #</td>
<td>E</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Approximate Weight</td>
<td>0.1 grams</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

RELIABILITY

<table>
<thead>
<tr>
<th>Test</th>
<th>Thermal Operating Temperature</th>
<th>240 hours continuous operation at Rated Power, at Maximum Rated Operating Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thermal Storage Temperature</td>
<td>240 hours storage at Minimum Rated Storage Temperatures</td>
</tr>
<tr>
<td></td>
<td>Thermal Shock Test</td>
<td>5 cycles of Minimum and Maximum Operating Temperature. Each cycle shall be set per diagram below and is three (3) hours long</td>
</tr>
<tr>
<td></td>
<td>Humidity Test</td>
<td>240 Hours at +40°C±2°C, 90-95%, RH</td>
</tr>
<tr>
<td></td>
<td>Operation Life Test</td>
<td>Must perform normal with program White Noise source at Rated Power for 100 hours per (EIA)</td>
</tr>
<tr>
<td></td>
<td>Termination Strength</td>
<td>Maximum pull of 0.5 kg strength for 3 seconds</td>
</tr>
<tr>
<td></td>
<td>Drop Test</td>
<td>Dropped naturally from 1 meter height onto the surface of 40 mm wooden board, 3 axes (X,Y,Z) directions, 3 times (6 times total)</td>
</tr>
<tr>
<td></td>
<td>Reliability Test Performance</td>
<td>Parts should conform to original performance within ±6 dB tested with Rated Power, after 3 hours of recovery period</td>
</tr>
<tr>
<td>Warranty</td>
<td>For a period of one (1) year from date of shipping under normal operating conditions</td>
<td></td>
</tr>
<tr>
<td>TYPICAL FREQUENCY RESPONSE</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DIMENSIONS

<table>
<thead>
<tr>
<th>Units in mm</th>
<th>Tolerance: ±0.3 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency (Hz)</td>
<td>Lower Limit (dB)</td>
</tr>
<tr>
<td>50</td>
<td>-6</td>
</tr>
<tr>
<td>100</td>
<td>-3</td>
</tr>
<tr>
<td>200</td>
<td>-3</td>
</tr>
<tr>
<td>1,000</td>
<td>0</td>
</tr>
<tr>
<td>2,000</td>
<td>-3</td>
</tr>
<tr>
<td>3,000</td>
<td>-3</td>
</tr>
<tr>
<td>5,000</td>
<td>-3</td>
</tr>
<tr>
<td>10,000</td>
<td>-8</td>
</tr>
</tbody>
</table>

The information contained herein is believed to be correct, but no guarantee or warranty, express or implied, with respect to accuracy, completeness or results is extended and no liability is assumed. Challenge Electronics reserves the right to make changes in any specification, data or material contained herein.
Appendix A5: Accelerometer

DE-ACCM3D Buffered ±3g Tri-axis Accelerometer

General Description
The DE-ACCM3D is a complete 3D ±3g analog accelerometer solution. It features integrated op amp buffers for direct connection to a microcontroller's analog inputs, or for driving heavier loads.

The on-board 3.3V regulator and decoupling capacitor give you great flexibility when powering the device, and can also be bypassed for operation down to 2.0V.

The DE-ACCM3D is designed to fit the DIP-16 form factor, making it suitable for breadboarding, prototyping, and insertion into standard chip sockets.

It is based on the Analog Devices ADXL330 for superior sensitivity and tighter accuracy tolerances.

Features
- Triple axis ±3g sensor range
- Up to 360mV/g sensitivity
- 50kHz bandwidth
- Operating voltage 3.5V to 15V (on-board regulator)
- Operating voltage 2.0V to 3.6V (without regulator)
- 3.3V regulator can power external microcontroller
- Reverse voltage protection
- Output short protected
- Standard DIP-16 form factor
- Integrated power supply decoupling
- Draws 0.9mA
- Can accurately drive 500Ω loads

Applications
- Motion, tilt and slope measurement
- Device positioning
- Shock sensing
- Vehicle acceleration logging
Performance features

Output buffers
A bare accelerometer chip has an output impedance of 35kΩ, which is unsuitable for obtaining reliable measurements when connected to an analog to digital converter. On the DE-ACOM3D, a quad rail to rail operational amplifier buffers the outputs from the ADXL330, greatly reducing output impedance. The absolute maximum load beyond which accuracy begins to seriously suffer is 2.3mA, or 500Ω.

Supply filtering
A 1μF ceramic bypass capacitor on the DE-ACOM3D provides excellent power supply decoupling. No external capacitors are necessary between Vcc and GND.

Output filtering and noise
A pair of 10μF capacitors limit the noise figure of the DE-ACOM3D, without overly sacrificing bandwidth. RMS noise is typically 7.3μg, and output bandwidth is 500Hz - making it suitable for high frequency sampling of acceleration.

Regulator Bypass
Most people will want to power DE-ACOM3D using the onboard 3.3V regulator. However, if you are designing an application that needs a lower operating voltage, you can bypass the voltage regulator. To do this, use the GND pin as normal. For the positive supply, add a wire to the exposed pad labeled BYP. The onboard 1μF capacitor will still be in parallel with the accelerometer chip, so additional capacitance is not necessary unless running from a noisy source.

This would be useful for e.g. an application powered directly by 2 AA batteries or a lithium ion battery. The minimum operating voltage when using bypass mode is 2.6V and the absolute maximum voltage that can be applied when bypassing the regulator is 3.6V.
Powering external devices

It is possible to use the DE ACCMD’s voltage regulator to power external devices that require 3.3V, such as a low voltage microcontroller. These devices must be externally powered so as to not overload the regulator! The maximum current that can be drawn in this way is 50mA, but ideally you should try keep things below 10mA. This diagram shows how to connect up an example microcontroller and all 3 axes.

![Diagram showing power connection to microcontroller](image)

Additional capacitance across the microcontroller’s power pins may be necessary, depending on your particular setup.

Protection features

Reverse voltage

In the event that you mix up VCC and GND, a P channel MOSFET will prevent current from flowing, protecting the DE ACCMD from damage. This protection is only designed to work with 5V voltages. Do not apply AC voltages to the power pins.

Output shorting

The operational amplifier driving the DE ACCMD’s outputs is capable of handling a direct short from the X, Y and Z outputs to ground for as long as you want.
Measuring acceleration and tilt
(Using onboard 3.3V supply)

The voltage outputs on the 3E-ACCM30 correspond to acceleration being experienced in the X, Y and Z directions. The output is logarithmic, so the output sensitivity (in mV/g) will depend on the supply voltage.

Sensitivity and accuracy

Here are some typical sensitivity values for common operating voltages:

<table>
<thead>
<tr>
<th>Operating voltage</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3V (default)</td>
<td>333 mV/g</td>
</tr>
<tr>
<td>3.0V</td>
<td>300 mV/g</td>
</tr>
<tr>
<td>2.0V</td>
<td>195 mV/g</td>
</tr>
</tbody>
</table>

Due to manufacturing variances when Analog Devices makes their accelerometer chips, these values aren’t always set in stone. Sensitivity can vary by up to 10% in extreme cases, and the 0g bias point can vary up to 5% on the X and Y axes, and 10% on the Z axis. For projects that require a very high degree of accuracy, we recommend that you incorporate measured calibrations into your hardware/software.
Example calculations

Voltage to acceleration example:
"With the 3.3V supply, the X output reads 2.95V. What acceleration does this correspond to?"
At 3.3V, the 0g point is approximately 1.66V
2.95V – 1.66V = 0.36V with respect to the 0g point.
At 3.3V, if sensitivity is 333mV/g, 0.36V / 333mV = 1.09g
Therefore the acceleration in the X direction is 1.09g.

Acceleration to voltage example:
"I am powering the DS-ACCGID with 2.0V. What voltage will correspond to an acceleration of -0.5g?"
At 2V, the 0g point is approximately 1.00V.
If sensitivity at 2V is 155mV/g, -0.5 * 155mV = -0.0975V with respect to the 0g point.
1.00V – 0.0975V = 0.9025V
Therefore you can expect a voltage of approximately 0.903V when experiencing an acceleration of -0.5g.

Voltage to tilt example:
"With a Vcc of 3.3V, and the accelerometer oriented flat and parallel to ground in my robot, Yout is 1.50V. When my robot goes uphill, Yout increases to 1.67V. What is the slope of the hill?"
1.67V – 1.50V = 0.17V with respect to the 0g point.
With a sensitivity of 300mV/g, 0.17 / 0.300 = 0.567g
Sin⁻¹ (0.567) = 34.5°
The slope of the hill is 34.5° in the Y axis.

Tilt to voltage example:
"I am making an arduino device that will sound an alarm if it is tilted more than 10° with respect to ground in any direction. I have measured the 3g bias point to be 1.701V, and I want to know what voltage to trigger the alarm at. I am using the onboard 3.3V source."
Sin (10°) = 0.1735 so acceleration with a tilt of 10° will be 0.1735g
0.1735g * 3.333V/g = 0.5779V with respect to the 0g point
1.701 – 0.5779 = 1.1231V
1.701 – 0.068 = 1.632V
Sound the alarm when the voltage reaches more than 1.725V or less than 1.642V.