Delft University of Technology

FACULTY MECHANICAL, MARITIME AND MATERIALS ENGINEERING
Department Marine and Transport Technology

Mekelweg 2
2628 CD Delft
the Netherlands
Phone +31 (0)15-2782889
Fax +31 (0)15-2781397
www.mtt.tudelft.nl

Specialization: Transport Engineering and Logistics

Report number: 2006.TL.7084

Title: **Management Summary: The Design of an Automatic Maintained Pipe-conveyor**

Author: S.S.Kalidien

Title (in Dutch) Management Samenvatting: Het Ontwerp van een Automatisch Onderhouden Pipe-bandtransporteur

Assignment: Master Thesis

Confidential: no

Initiator (university): prof.dr.ir. G. Lodewijks

Initiator (company): TU Delft

Supervisor: ir. K. Drenth

Date: OCT 1, 2006

1 Introduction

The pipe conveyor is a conveyor system that encloses bulk material, thus eliminating the risk of dust contamination. The idlers of these pipe-conveyors are components in the conveyor that ought to be regularly maintained. Defect in idlers can damage the belt, the most expensive component of the conveyor. Nowadays expensive maintenance personnel is used to inspect the idlers, however this very costly and dangerous. Automation of maintenance is a promising alternative for outsourcing maintenance. In order to optimize maintenance efforts, the concept of *intelligent maintenance* is introduced (see [1], [2], and [3]). A powered maintenance trolley that can travel autonomously over the structure of a belt conveyor is adapted as a platform of the maintenance system. A maintenance robot, which is positioned on the moving trolley, will be used to replace damaged idlers. However, the replacement procedure (sensor system/locking system) of the robot is yet to be investigated.
The main objective of this study is therefore is to design a fully automated maintained pipe-conveyor, which can replace worn out/damaged idlers, without any help of external personnel.

2 Model Description Pipe-conveyor

Functional principle

The pipe conveyor, which as its name suggests functions in all basic facets as a conventional belt conveyor, but after being fed and prior to being discharged the belt is formed into a tubular or pipe shape for the vast majority of its journey. There are six idlers needed to enclose the belt, three on the front and three at the back (see figure 1)

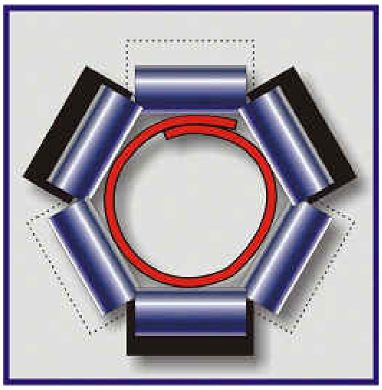

Figure 1 Six idlers for belt

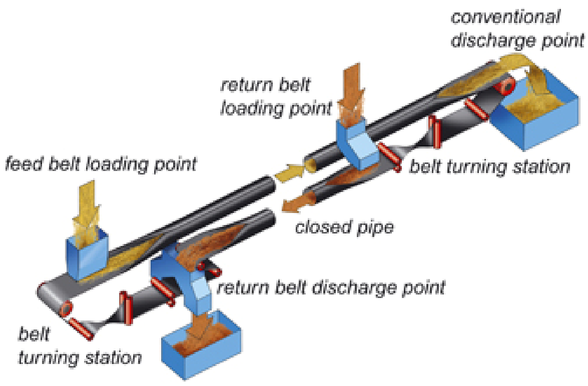

Figure 2 Components pipe-conveyor

The pipe conveyor uses the same standard components as the conventional (see figure 2):

- An endless, rubberized flat belt is suspended between pulleys at either end and supported along its length by a number of rotating idler rollers.
- The belt is driven via one of the pulleys (usually the head pulley) and the tension in the belt is maintained by using a sliding pulley which is tied to a gravity take-up unit
- The material is loaded onto the conveyor at the tail-end via a chute and is transported along the carrying-side to the head-end where it discharges into a discharge point which guides the product onto the downstream equipment. The belt opens by itself before the material discharge point is reached; the material is discharged.
- Once the material has been discharged from the carrying belt, the return belt is guided back to the tail pulley on return idlers.

- The belt turning station at the discharge point allows for additional material feeding for material transport on the belt return.

Advantages of the pipe-conveyor

- Environmental acceptable; the belt is enclosed thus no spillage of material
- Ability to handle sharp radii; eliminate transfers that are normally necessary when there is a relatively sharp change in belt direction.
- Ability to handle steep angles of Inclination: the pipe conveyor can negotiate much steeper angles of inclination than a conventional belt conveyor. With the steeper inclination the conveyor can be made shorter, providing further economics or perhaps making it the only viable solution due to space or property restrictions
- Pipe-form return belt: this not only allows the conveyor to handle the same curved route as the carrying strand but it also encloses the dirty side of the belt.
- Same volume of material: the pipe conveyor can transport the same volume of material as the conventional belt conveyor that has typically 2.5 to 3 times the belt size of a given pipe diameter.
- Standard components: the same standard components that are used for the conventional conveyors are also used for the pipe conveyor.
- Conveyance on top and return stand: as with a conventional conveyor, material can be conveyed on the return strand in addition to that being carried on the top strand (see figure 2)

3 Project Criteria

Aim and scope

This report will discuss automation of maintenance of belt conveyor systems, in particular of idler rolls. The scope of this report can be summarised as follows:

The main objective is to design a fully automated maintained pipe-conveyor, which can replace worn out/damaged idlers, without any help of external personnel.

The following subjects will be investigated:
- Selection of sensor instruments for inspection; the idlers of the pipe conveyor must be inspected, therefore a selection must be made of the available sensor equipment.
- Selection of a maintenance robot; the maintenance robot must be fully automated, without interference of personnel.
- Design of automatically replaceable worn-out idlers; the design of the idlers should be a simple click-system, so the maintenance robot can replace them easily.
- Needed tools for robot to (re)place the idlers.

System Boundary

The system boundary encloses the research field. In this case the pipe-belt, idlers, idler-panel, support-structure and the robot with trolley are the objectives to be researched. See figure 3

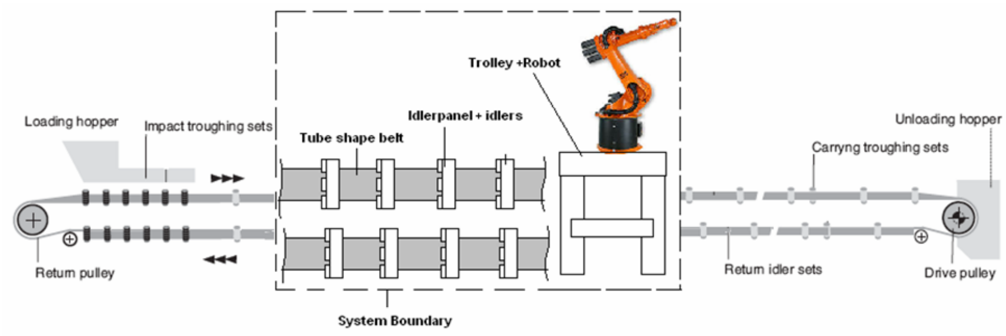

Figure 3 System Boundary

Design parameters pipe-conveyor

The following data are typically given for a design of a Pipe-conveyor:

- Length conveyor (L) [m]
- Capacity(C) [ton/hrs]
- Elevation(Δh) [m]
- Number of curves (n)
- Density of transported good (ρ) [kg/m^3]
- Filling rate (λ) [%]

For the design of the idlers, the total load on the idlers must be determined, see figure 4 for calculation steps:

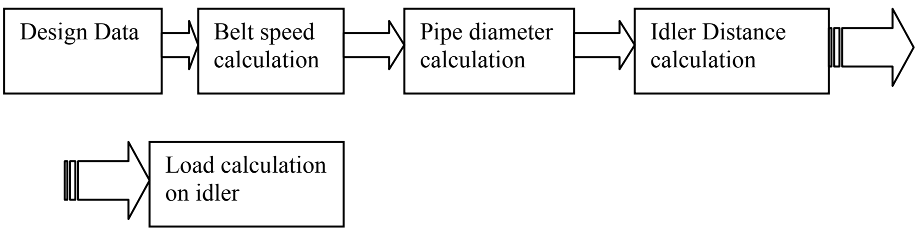

Figure 4 Calculation steps to determine load on idler

4 Automatic Maintenance

In general, maintenance on belt conveyor systems can be divided into two parts:

- Inspection or condition monitoring of total system (belt and idlers)
- Replacement and/or reparation (in short servicing) of its components (idlers).

Maintenance types

There are four typical types of maintenance [1]:

- **preventive maintenance:** calendar based,
- **random maintenance:** opportunity based,
- **corrective maintenance:** emergency based,
- **predictive maintenance:** condition based,

Only a predictive maintenance concept qualifies for application in an intelligent maintenance system that enables maintenance automation. Applied to belt conveyor systems the information gathered from a system is information on the life expectancy of individual components for idler rolls. This information leads to a decision either to inspect a certain idler station and the rolls more frequently or to change a roll for a new roll. Repairing in fact here means changing one roll for another.

Maintenance strategy

Best Strategy for inspection system (see [2] and [3]): More inspections are carried out when a bearing gets to the end of its lifetime. The maintenance robot carries out the inspection and the replacement activities on the forward journey, and has no activity on the return journey.

Data acquisition techniques

For rotating conveyor components the following measurement techniques are used:

1. Vibration (and or acoustical) measurement techniques.
2. Temperature measurement techniques (thermography).
3. Ultrasonic measurement techniques (ultrasonic)
4. Tribology (lubrication oil analysis and wear particle analysis).
5. Force and torque measurements.

Only vibration- and temperature measurements techniques were found useful for further investigation.

Vibration measurement techniques
Bearings containing rolling elements like rollers or balls, produce vibration excitation forces at specific frequencies dependent on the bearing geometry and rotation speed. These vibration frequencies are called bearing tones. All such bearings, regardless of their condition, will produce some level of bearing tones. The important fact is that they increase in level by *bearing defects* and are repetitive. These defects can be detected using an acoustical or vibration sensor in combination with a high-pass low-pass filter (see figure 5).

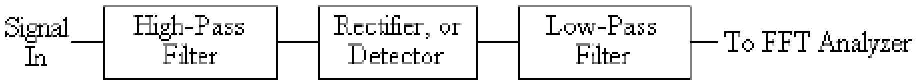

Figure 5 Filter diagram for detecting defects in bearings

Thermography measurement
Damaged bearings will show temperature increase. The temperature increase can be detected by infrared (i.r) imaging or thermometers.

External or 'built-in' sensors?

Externally placed sensors, have a clear advantage in comparison with 'built-in' sensors in the cost department; only the trolley has to be equipped with sensors:

1. the empowered trolley with the sensor will move along the idlers;
2. No structure adaptation of the idlers: the sensors are measuring contact-less

Selection of sensor equipment

Main criteria:

- *Total cost of the sensor system*: The total investment of the maintenance system must be less than the costs of outsource personnel. Above this value the system is not profitable and therefore not recommended.
- *Accuracy of sensor-system*: The repeatability and accuracy of each data is extreme important in predictive maintenance.
- *Reliability of sensor system*: The sensors must be resistant to weather influences and other anomalies (crossover flying planes, dust of material etc.)
- *Measurement range of sensor*: The sensors are placed externally from the rolls. The measurement range of the sensor must be within the placement-distance for accurate results.

For maintenance purposes, by using externally placed sensors, the laser vibrometer[14] (figure 6) is the best suited sensor for the system. (Optional, the IR-thermometer (figure 7) can be used as verification tool in combination with the vibrometer).

Figure 6 Laser Vibrometer

Figure 7 IR-Thermometer

Mounting of sensor equipment

The main limit of the laser vibrometer is the requirement of isolation from structure vibrations, which can be achieved by designing vibration isolation system and mechanical filtering in the frequency of interest. In it most basic form, a vibration isolator is a spring/dashpot combination with stiffness (like rubber) and damping coefficient carefully chosen to isolate the instrument from vibrations if its surroundings. There are manufacturers which can provide with the correct vibration-isolator. Therefore the excitation frequencies in the total system have to be calculated, this will be done after designing the complete support structure.

Robotics

Industrial robot systems consist of four major subsystems:

1. Mechanical unit;
2. Drive;
3. Control system;
4. Tooling.

The advanced (six degrees of freedom) industrial robot is qualified for maintenance purposes and is therefore a logical choice. The bigger companies are: MOTOMAN, KAWASAKI, FANUC, ABB, PANASONIC and NACHI. The prices of an industrial robot do largely depend on the size of the robot, yet the functionality for most six-degrees industrial robots is the same. The tools the robots are using combined with the programming, form the major percentage of the cost

Replacement options and tooling for robot

The standard basic form of an idler is not usable for automatic replacement purposes. A new design of the idler (idler roll, shaft, bracket etc.) is required.

The only plausible way for replacing the idlers by a robot arm is when the idlers are one-sided mounted. There are two acceptable solutions to tool the robot (lower centre idler is taken as example):

1. Concept 1(figure 8a): The robot-arm uses a 'shuffle' like tool to lift the belt from the idler and a gripper to (un)lock the idler-unit from the bracket.

- The shuffle lifts the belt from the idler (step 1).
- The griper encloses the idler and (un)locks it from the bracket (step 2,3 and 4)

2. Concept 2 (figure 8b): Different approach direction of the robot:

- The robot approaches the belt from underneath and shuffles the belt upwards (rolls can placed on the shuffle to keep the friction low), the arm of the robot moves then with the gripper in an open state to the idler (step 1)
- When the gripper has reached the shaft of the idler, it will enclose the idler-unit (step 2).
- The gripper will then (un)lock the idler-unit (step 3 and 4)

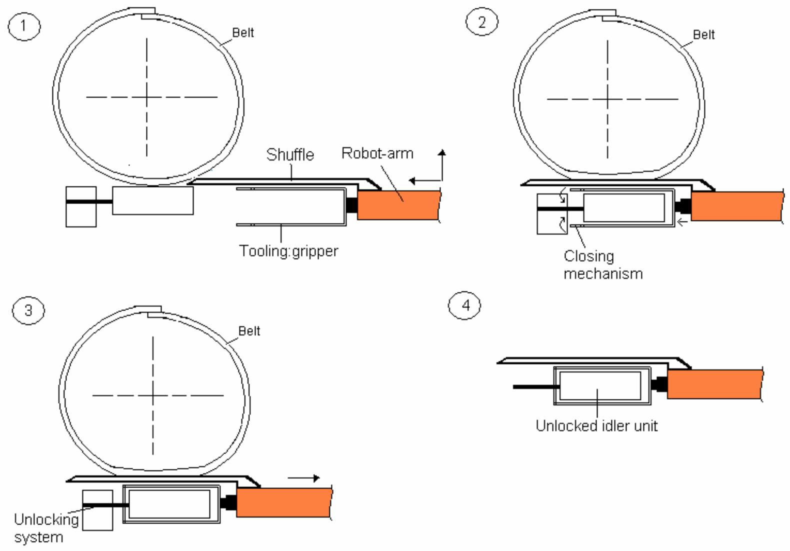

Figure 8a Concept 1 for tooling the robot-arm

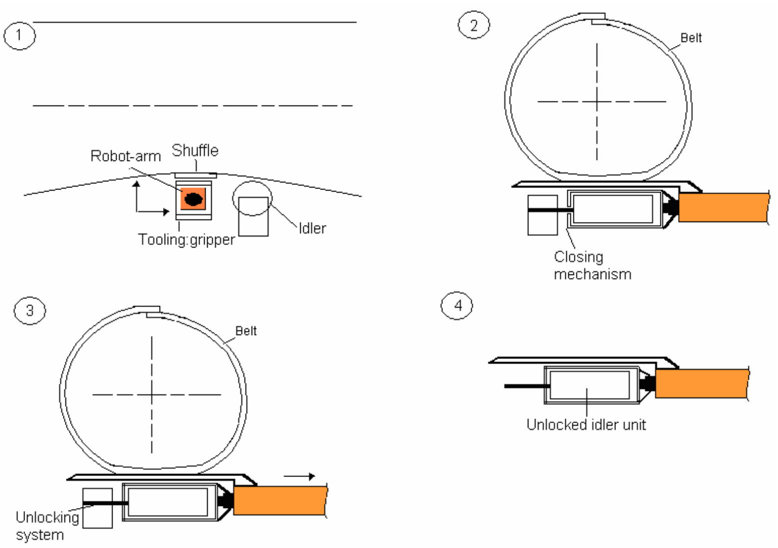

Figure 8b Concept 2 for tooling the robot-arm

5 Belt selection

In order to design an appropriate one-sided mounted idler, the normal forces on the idlers must be calculated. The normal forces on the idler are the result of the mass of belt and mass of bulk.
The mass of the bulk can be calculated with the given capacity and determined belt speed.

However, to determine the mass of the belt (specific mass in kg/m), the right belt type must be selected. It's an iterative process; the process can loop two or three times, before the right belt type can be chosen.
In the figure 9 a flowchart is given in which the calculation steps are given in order to select the right belt and finally to design the idler.

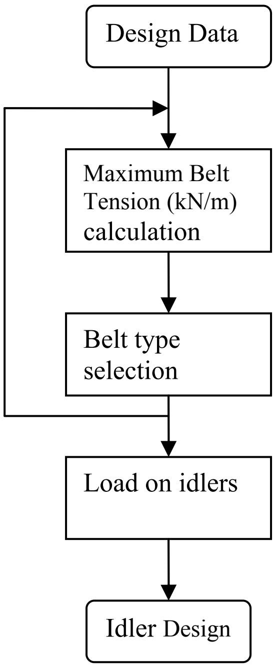

Figure 9 Flowchart for belt selection and idler Design

Maximum belt tension calculation

Two standards are currently used to calculate the maximum belt tension: DIN 22101(Europe) and CEMA [4] (America). Although the DIN 22101 is more widely accepted, there is little or less known about tensile force calculations for Pipe-Conveyors, which are using this standard. However some German and American articles are available using the CEMA standard.
In LOEFFLER[5], the CEMA equations are modified so they can be used for the pipe-conveyor preliminary design. By calculating the total resistance force (T_e) in the pipe-belt, the maximum tensile force (T_1) in the belt can be calculated.
The total resistance force (T_e) in the pipe-belt is the sum of three types of tensile forces:

1. The tensile force required to move the belt horizontally (T_{horz});
2. The tensile force required to lift or lower the load (T_{lift});
3. Additional Tensile factors (T_{misc}).

The following parameters were given for calculations purposes (table 1):

Preliminary design data	
Material characteristics	• Coal • lump size: 150 to 200 mm

	• very abrasive • density: 850 kg/m^3
Horizontal Length	4500m
Elevation	0 m
Capacity	1600 ton/hrs
Number of curves	4, with a maximum of brake angle 30 degrees
Number of Circular forming sections	4

Table 1 Calculation Parameters for Belt Selection

Using an iterative process and given parameters, the following results are obtained (see table 2):

Calculation results	
Filling rate cross-sectional area pipe	66%
Belt speed	5 m/s
Pipe Diameter	450 mm
Belt Width	1650 mm
Idler Distance	170 mm
Maximum tensile Force in Belt (T_1)	200 kN
Specific bulk mass	89 kg/m
Belt Characteristics	• Steelcord carcass • Belt class: ST1000 • specific belt mass: 41 kg/m • belt thickness :17,7 mm • Safety Factor: 8

Table 2 Calculation results belt selection

Belt selection.

From various papers, its clear that for longer pipe-conveyors (>1,5 km), steelcord belts (see figure 10) are more often used. Steelcord has the advantage of very low elongation, high tensile strengths and high impact resistance. In the future when KEVLAR fabrics are better evolved and priced, it will be a better alternative then Steelcord.

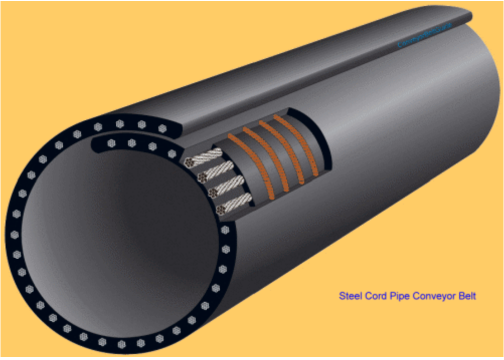

Figure 10 Steelcord pipe-belt

6 Idler Design

Idlers are an important component in any conveyor system as they are used to support the conveyor belt and the load carried on the belt.
The following parts are standard in an idler (figure 11):

- Roll-shell
- Bearings
- Shaft
- Other components like: bracket, sealings, endcaps and fixations (circlips).

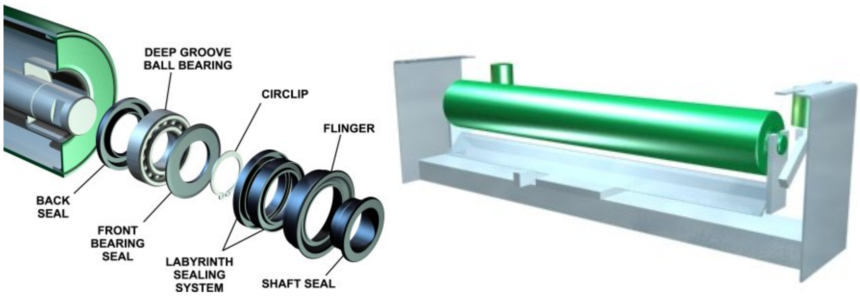

Figure 11 Idler components

The design of the one-sided mounted idler differs from the standard idler, only in the need of a (un)locking system for the robot. The bracket and its components have therefore to be adjusted. The following steps are needed for a successful design of the idler (see figure 12) it is a continuation of the earlier given scheme (figure 9), were ↔ denotes an iterative process.

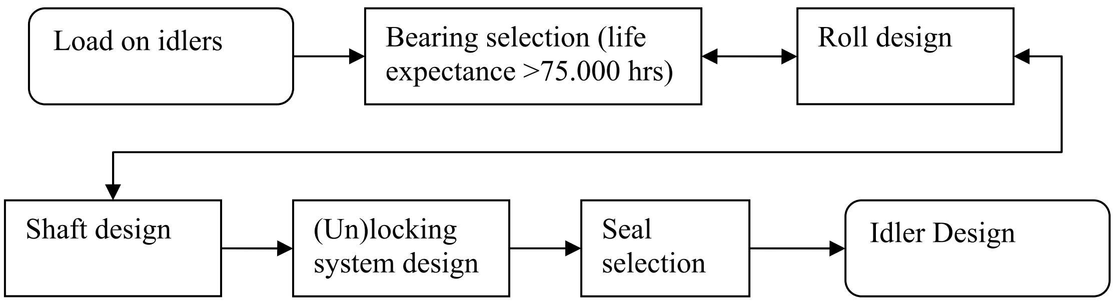

Figure 12 Flowchart for idler design

Load on idlers

The load on the idler can be subdivided in the following categories:

1. The load due mass of the material;
2. The load due gravity load of the belt;
3. The load due pipe-forming of the belt;
4. Additional loads

<u>ad 1) Load due mass of the material:</u>

Because there isn't any comparative study available for the load due mass on idlers in Pipe-conveyors, an estimation of the load is made based on principles, which are used for the conventional throughed conveyors; Behrens [6].

It is safe to say, in the case of the pipe conveyor, where the idler throughing angle(θ) is 60 degrees; the resulting force on the centre idler, is larger then the load on the left or right idler and therefore the roll dimensions are based on the calculation results obtained from the centre roll.

ad 2) The load due gravity load of the belt

The total load due the gravity load of the belt can be calculated by multiplying the idler spacing and the specific belt mass accounting for the belt sag (Lodewijks [7].

ad 3) The load due pipe-forming of the belt

A pipe-forming force is needed to maintain the pipe shape of the belt. As stated earlier; little literature is available about calculations in the pipe-conveyor. Wesemeier [8] from the Magdeburg University has formulated a method to calculate the pipe-forming force on idlers.
The most important conclusions are that the pipe-forming force is essentially determined by:

- Normal forces on the rolls due circular enclosing (deformation) of the belt;
- The working tensile force (T) and gap height at the overlap of the pipe.

ad 4) Additional loads

There are two main additional loads worthwhile recognizing:

1. Normal forces on shaft due to rotating elements like bearings and roll shell.
2. Normal force due to convex curves.

Adding all the loads on the idlers by using the data of table 1 and 2: the total load on the lower centre idler is the largest and is about: 3kN

7 Bearing selection

Bearings in the construction of the idler are to support and conduct moving parts along each other, like the rotating roll of the idler. The bearing will then transmit the acting forces on the shaft to other parts of the structure. For the pipe-conveyor frequently **deep-groove ball** bearings from the **series 62xx and 63xx** are used, because the low cost and different application capabilities.

By calculating the life-span of bearings, the appropriate bearing can be selected for the idler. The most idlers are selected to ensure a compliance of ***75.000*** hour bearing life criterion (SKF [9]). The following results are obtained:

- The shaft's diameter has to be notched down if smaller bearings are used (smaller bearings are cheaper). It also fixated the bearings in the axial direction of the shaft. However while decreasing the diameter of the shaft, the allowable strength and stiffness of the shaft must not be exceeded.
- Bearing type 6306 can be used for both the centre- as the side idlers, without losing the minimum life-expectance of 75.000 hours.

8 Roll design

The rolls (roller-shells), bearings and shaft of the idler are so inter-related that the dimensioning of the roll is an iterative process.

Standard used diameters for the conveyor rolls-shells are (from SABS and CEMA [4]):
89 mm, 127 mm, 133 mm and 152mm, larger rolls are not likely used.

Selection of a proper roll-diameter requires several calculations:

1. *Life-span calculations*: using the proposed belt speed and minimum bearing-life as a reference.
2. *Power consumption calculation*: the power difference of using large roll diameters in comparison of small roll diameters.
3. *Cost calculations*: the price difference between small and large roll diameters.

The ***proper diameter of the roll for the calculation example*** is found by ***optimizing these relations***:

Ad 1)

- Increasing the roller-diameter, decreases the number of revolutions (angular velocity ω(rad/s)) of the roll and therefore increases the bearing-life.
- The roll-life and bearing-life are related with each other with a constant factor (which is the product of fatigue chances of the two bearings). The bearing-life one bearing of 75.000 hours therefore isn't exactly the same as the life-expectance of the whole roll (with two bearings). For the calculation example: Only with larger roll diameters, like the D_2 (127 mm), the 75.000 hours life-span is feasible, D_1 See figure 13, where P = equivalent load, D_i = diameter of the roll, v = belt speed and L_{10} = life span of roll.

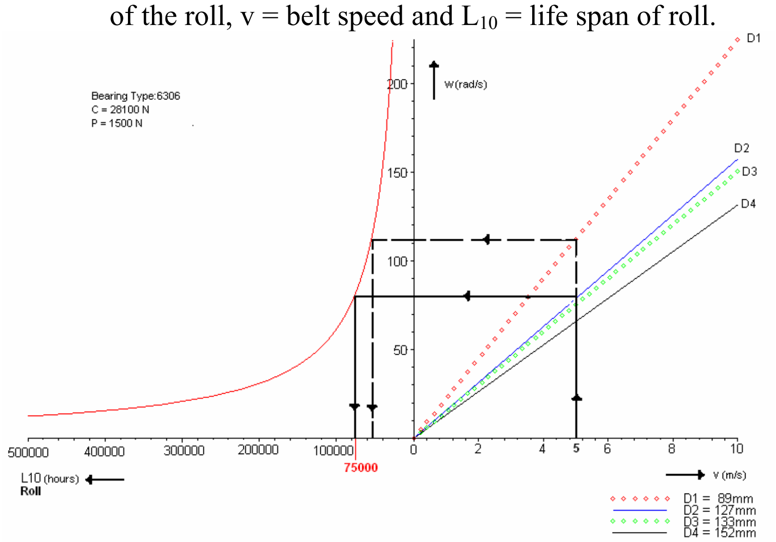

Figure 13 Example roll-life calculation for various diameters rolls

Ad 2)
Larger roll diameters will relatively draw less power from the system then smaller roll diameters. Yet to overcome 'dynamic drag' or 'overloading the motor' (by increasing the total rotational inertia) the diameter increase of the roll is limited.

Ad 3)
Increasing the roll diameter requires a large investment. To hold the total payback time of the system at a minimum, the diameter should also be kept as low as possible. For the calculation example: the minimum required diameter of the roll is determined by the bearing-life criteria of 75.000 hours, therefore **127 mm** is chosen as diameter for the roll for the calculation example.
Basic concept roll

A basic concept for the roll is derived (figure 14), by using examples from manufacturers of standard rollers.

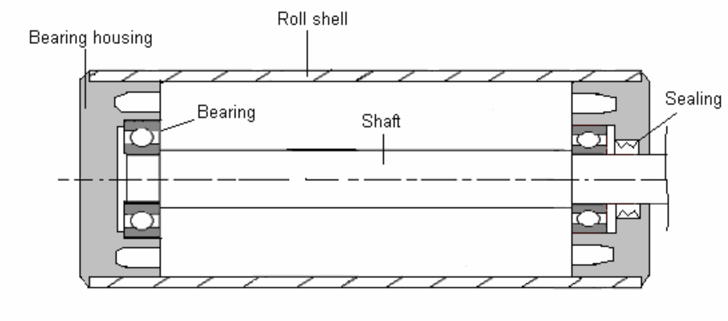

Figure 14 Basic concept roll

The following components are used:

- Two bearing housings with seals which are pressed to fit in the roll.
- Roll shell from precise tubing metal or tubing polymer.

The concept has the following advantages:

- Cost effective and flexible; standard tube-profiles can be bought; this requires no extra injection mould machine. When other belt widths are used, the tube-length can easily be adjusted (the bearing housings are inter-changeable with different tube lengths).
- Lower rotational inertia; minimizes the belt tension during acceleration and deceleration of the belt.
- Easy installation of the bearing housings in roll; the housings can be pressed to fit (polymer) or in a metal or polymer roll shell.

Material type selection of roller

Special charts are available in [10] where the stiffness (E) and breaking strength (σ_f) for each material are divided by the density (ρ), it shows the specific modulus (E/ρ) against the specific strength (σ_f/ρ). Using these tables, the right material type is chosen using the design criteria: **ABS**, has performance/ cost/ weight wise the best ratio's and is therefore the best material type for the roll shell. The required thickness of the shell for the calculation example is then 3 mm.

Balancing requirements roll and critical speed

- Although a roll can never be perfectly in balance, the unbalance distance (distance between the centre of mass and principal axis of inertia of the body) must be in certain limits to not let the roller deflect too much while rotating. Using the balancing standards ISO 1940-1 (1984, [12]) G= 6.3, the maximum distance (e) of the unbalance of the roll can be set. The distance e is limited too keep the amplitude of the vibrations low.
- Of primary concerns in the design of the rotating idler is the vibration phenomenon of *critical angular velocity* [11].For the calculation example:
  - The angular velocity of the roll acquired by the belt speed is much lower than the critical angular velocity of the roll, thus no resonance will occur and no bearings will be damaged.
  - Because the amplitude of the roll-vibration at balancing grade 6.3 is low, it will not interfere the measurements of the laser-vibrometer.

9 Shaft Design

The length of the shaft is determined by the roll dimensions (L_{roll}), gripping point robot (L_{Robot}) and the idler-bracket ($L_{bracket}$) (see figure 15). For the calculation example the shaft length is estimated at 410 mm.

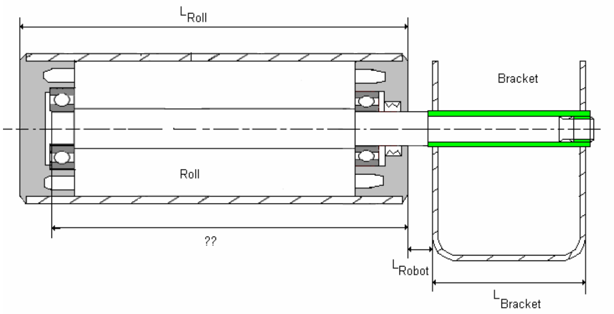

Figure 15 Shaft length estimation

The diameter of the shaft depends on a couple of factors:

- In order to prevent the shaft from yielding, the total *maximum stress* due the loading of the material and belt in the shaft need to be calculated and compared with the allowable strength of the material. In the one-sided mounted idler, the maximum bending moment determines the maximum stress in the shaft. For the calculation example: Material type E-295 (yield strength), with safety-factor 1,5 is selected. The maximum bending moment is for the calculation example at point O (see figure 16) and is about 495000 Nmm. The minimum required diameter due stress considerations is then 30 mm.

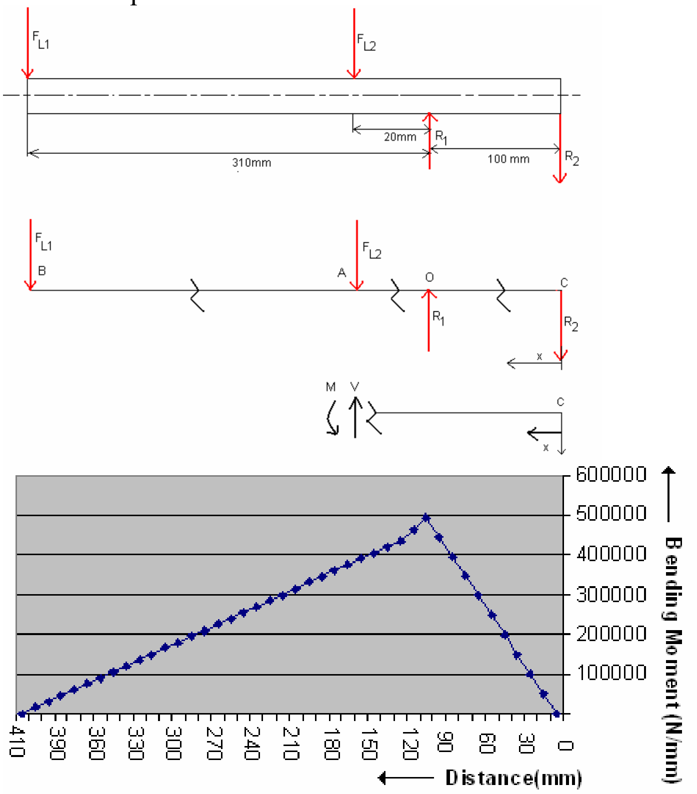

Figure 16 F.B.D and bending moment of shaft

- The deflection of the shaft has to be limited within the misalignment limits of the bearing and seal assemblies. After calculation of the deflection with standard formulas (see figure 17), it is proved that the calculated diameter of 30 mm is not enough to fulfil the requirements of the allowable deflection. The minimum diameter of the shaft is therefore increased to 35 mm.

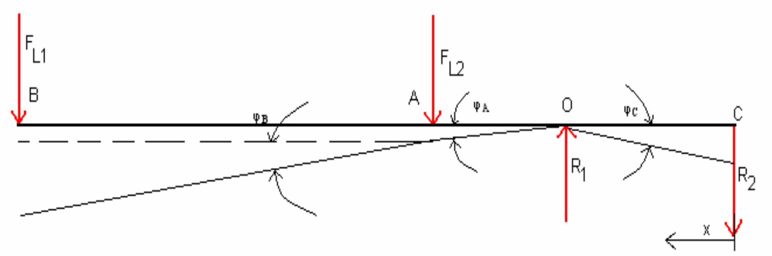

Figure 17 F.B.D Deflection of shaft

10 (Un)locking system

The new designed idlers are one-sided mounted, to make the robot capable of replacing the idlers an (un)locking system must be designed, which is capable of simple (de)connecting the idlers.

- An U-shaped steel bracket is designed (figure 18 (left)), which can be mounted (with bolds) on the idler-panel, the (un)locking mechanism is then fitted between the legs of the U-shape. A possible solution to increase the stiffness of the bracket: inserting ribs or gulfs (see figure 18 (right)).

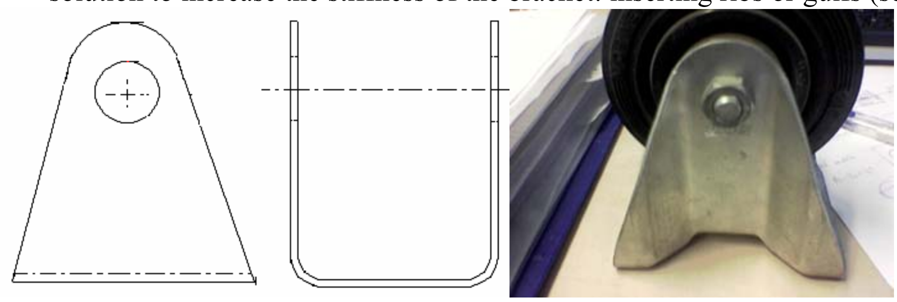

Figure 18 Bracket 2: U-shaped bracket

- Training idlers are needed to detect belt misalignment and automatically re-align the belt (see figure 19). The idler needs in this case to rotate. The earlier developed bracket can also be used for the training idler, however the bracket must be placed on a L-shape base just like a standard training idler (see figure 20). In the bracket, the slotted holes are needed for lateral adjustment, a spill in the middle, will make the bracket capable for rotating (see figure 21).

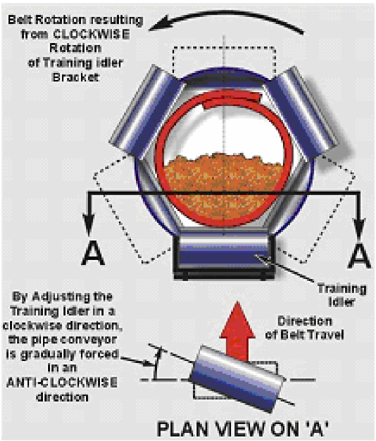

Figure 19 Belt misalignment detection

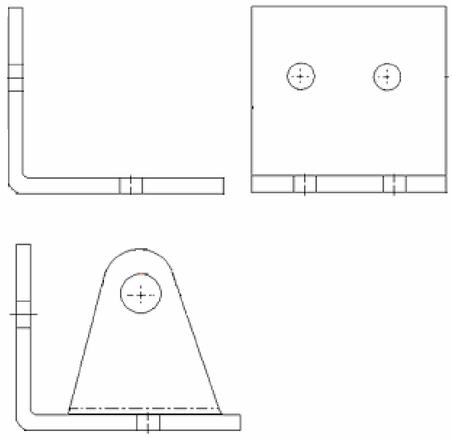

Figure 20 L-shaped base training idler

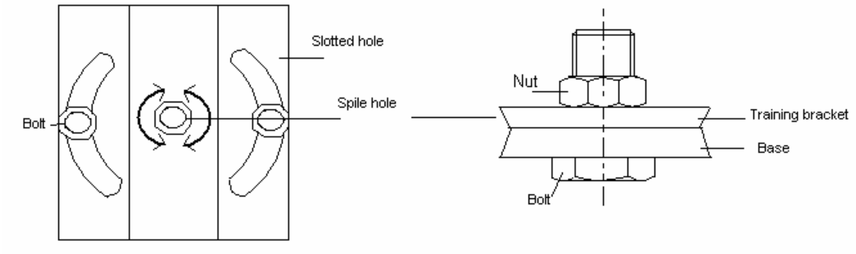

Figure 21 Idler bracket with spill and slotted holes

- There are a lot of examples of simple (un)locking systems found in ‘daily’ used products, like pencils, blender machines, electrical toothbrushes, phone-utp-connections etc. These products can be used, to find design concepts for the (un)locking of the idler. For the one-sided mounted idler a glass jar with screw cover design is used (see figure 22). On the shaft-end helical sub-threads are applied, this can be processed with simple roll-cutting machinery.

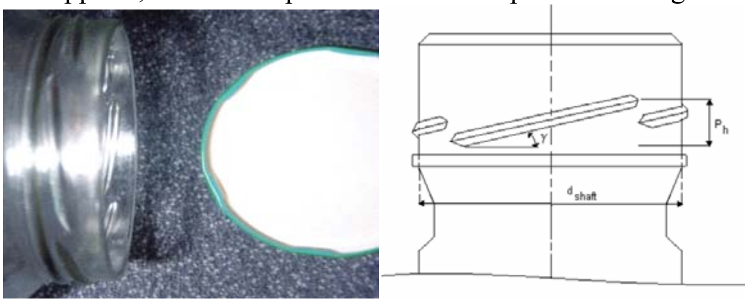

Figure 22 Glass jar with screw cover

- To position and centre the shaft a helical tube is used, which is fusion welded on the bracket. The helical tube also protects the shaft-end from corrosion. A docking system that reflects the screw cover is glued in the bracket (see figure 23 and figure 29 for more details).

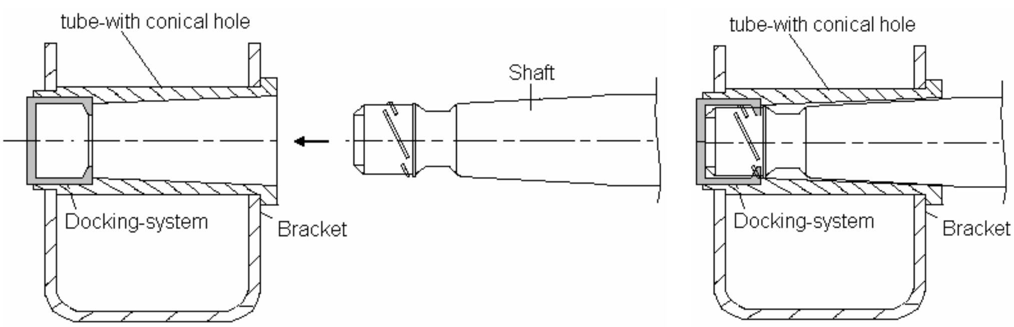

Figure 23 (un)locking system for idler-unit

- For the (un)locking of the roll-unit from the bracket, the shaft needs to be adjusted at the grabbing point. A simple hexagonal shape is chosen (see figure 24), the shaft is therefore trimmed down. At the downside of this system, the hexagonal shape has a lower moment of inertia. To fulfil the strength criteria of the shaft, another steel type is needed with a higher failure strength. For the calculation example steel E360 is chosen, with a failure strength (yield strength) of 360 N/mm^2.

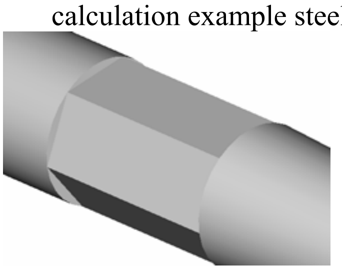

Figure 24 Trimmed down shaft

11 Seals and bearing fixations

Seals

To fix and prevent the bearings from contaminants, seals and fixation points are installed.
Bearing seals have two main functions:

1. to prevent lubricant from leaking out;
2. to keep the grease in the bearing and eject contaminates from the seal so that they don't build up and lead to seal damage.

Sealing devices for rolling bearings fall into two main classifications: contact and non-contact types. With non-contacting seals very little frictional heat is generated making non-contact seals very suitable for high speed application like the idlers of the pipe-conveyor.
As primary seal a non-contacting labyrinth seal will be used; Labyrinth seals (see figure 25) employ a multistage labyrinth design which elongates the passage, thus improving the sealing effectiveness. As secondary seals Nilos ring and O-rings can be used (see figure 26).

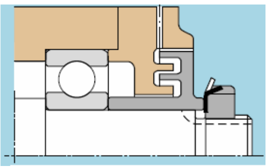

Figure 25 Axial labyrinth seal

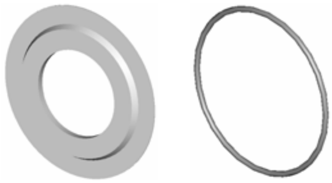

Figure 26 Secondary seals (Left:Nilos-ring,Right: O-ring)

Bearing arrangement

The bearing arrangement of a rotating machine component, e.g. a shaft, generally requires two bearings to support and locate the component radially and axially relative to the stationary part of the machine, such as a housing. As a rule one of the two bearing housings must house a non-locating bearing and the other a locating bearing (see figure 27):

- The locating bearing at one end of the shaft provides radial support and at the same time locates the shaft axially in both directions. It must, therefore, be fixed in position both on the shaft and in the housing.
- The non-locating bearing at the other end of the shaft provides radial support only. It must also enable axial displacement so that the bearings do not mutually stress each other, e.g. when the shaft length changes as a result of thermal expansion.

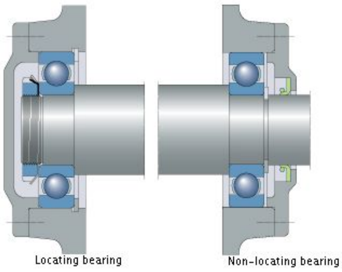

Figure 27 Example of locating and non-locating bearing (SKF[9]).

Sealing arrangement

From idler manufacturers, like HABETS, LUFF Industries, MELCO an ERIKS, sealing and bearing arrangements for the idlers can be obtained. The following arrangements can be used for the fixation and protection of the bearings and shaft in the one-sided mounted idler:

- Polymer bearing housings for bearing and sealing positioning on the shaft.
- Outer ring seals (weather seals); to keep contaminants from the environment outside the roll
- Nilos rings; to keep contaminants out from inside of roll, like rust.
- Circlips to fixate the bearings on the shaft or housing.
- O-ring is used as a gasket and seals through its deformation.

12 Final design of Idler

All needed components of the idler are determined; the idler parts are drawn in Pro-E (see for total view figure 28 and detailed cross-section view figure 29):

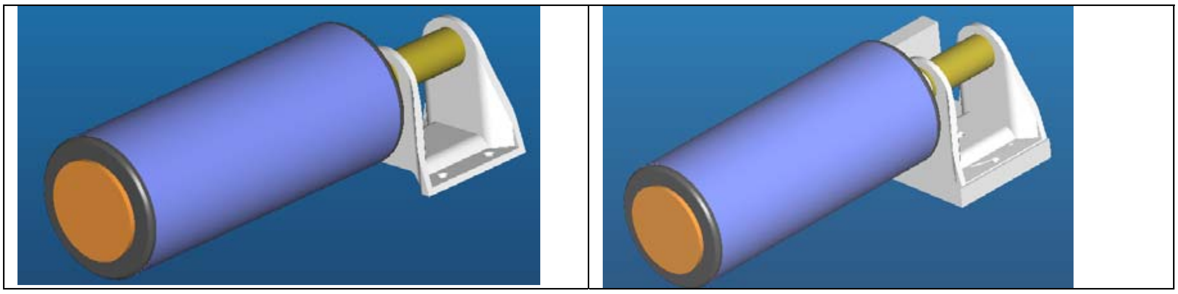

Figure 28 Total view of normal idler and training idler

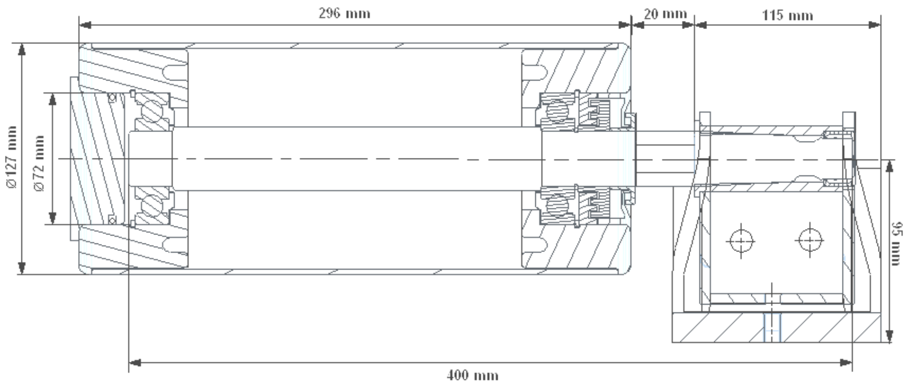

Figure 29 Detailed cross-section view of training idler

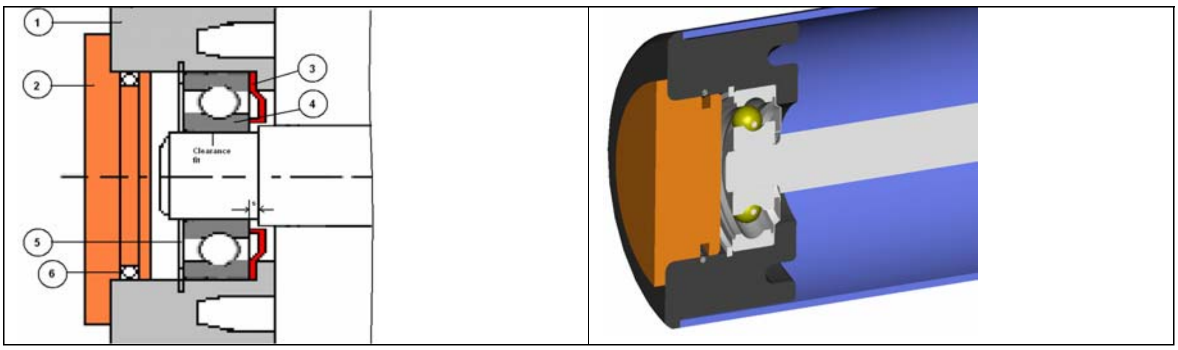

Figure 30 Sealing arrangement bearing house 1

Notes on figure 30:

- (1) Polymer bearing housing which is injection moulded from Polyurethane (P.U). The polymer components can be interconnected with ultrasonic-welding or gluing.

- (2) Outer ring seal also from P.U to keep the bearing contaminant free (extra weather protection).
- (3) Nilos ring for internal sealing against contaminants from the inside of the roll (rust etc.)
- (4) Deep groove ball bearing (6306 for the calculation example).
- (5) Circlip DIN472 is needed to fix the bearing axially in the housing. The circlip- and groove dimensions can be found in the appendix.
- (6) The O-ring is in the bearing housing used as a gasket and seals it through its deformation.

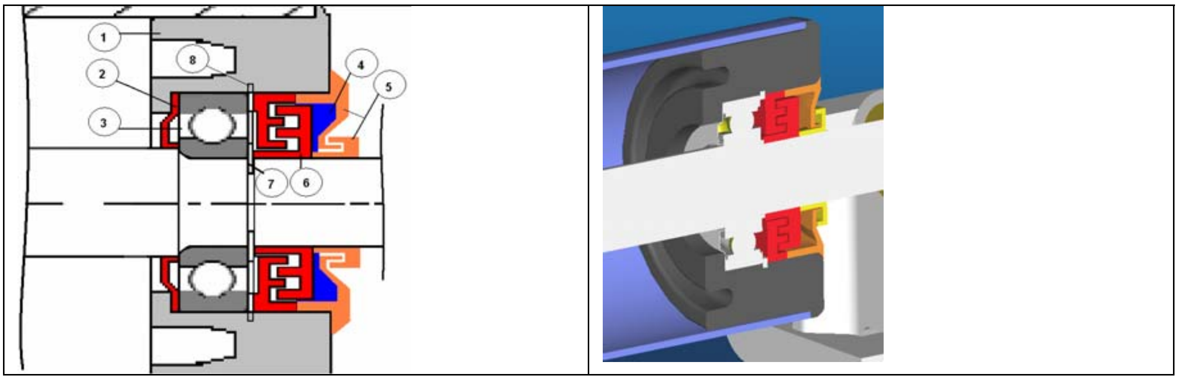

Figure 31 Sealing arrangement bearing house 2

Notes on figure 31:

- (1) Polymer bearing housing (ABS Hi-100) same as bearing housing 1.
- (2) The Nilos ring is used for the internal sealing (see also bearing housing 1).
- (3) The deep groove ball bearing is located on both sides (interference fit).
- (4) The grease free chamber is for extra precaution against contaminants
- (5) The polymer outer ring seal is made of the same material as the housing, Polyurethane and is needed to enclose the roll.
- (6) The Labyrinth seal is the main non-contact sealing equipment against the contaminants (manufacturers: HABETS, ERICS and LUFF Industries).
- (7) Circlip Din 471 to fix the bearing axially in the shaft.
- (8) Circlip Din 472 to fix the baring axially in the bearing house.

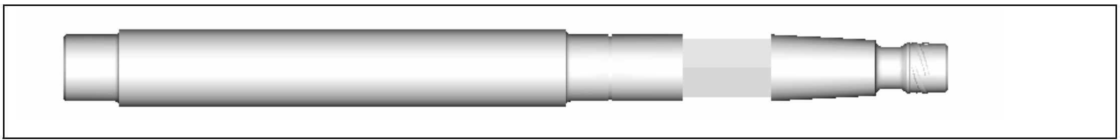

Figure 32 Final shaft design

Figure 33 Final bracket design (normal idler/training idler)

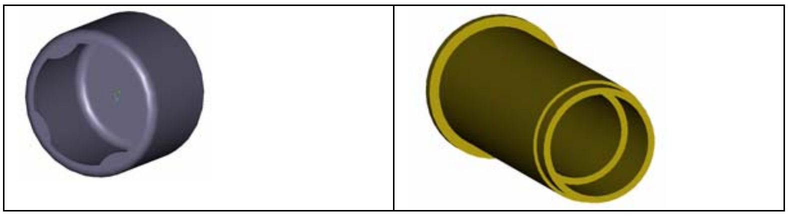

Figure 34 (un)locking system for idler-unit

13 Support structure

The triangular structure has obvious advantages over other available structures; it isn't only more economical but also has the advantage to use the structure as a support for the maintenance trolley.

In the triangular structure are hexagonal idler panels incorporated; these are needed to install the idlers in hexagonal configuration and keeping the belt in a pipe-shape (see figure 35). The panels are made from standard pressed steel.

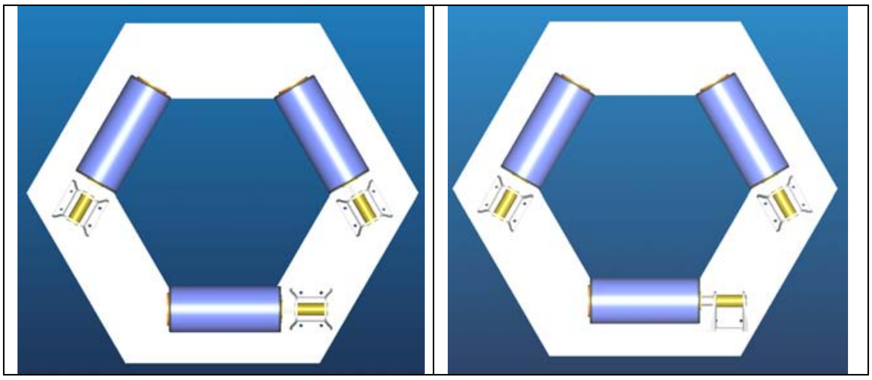

Figure 35 Hexagonal Idler panel (left: standard configuration, right: configuration with training idler).

The dimensions of the supporting parts in the structure are calculated with basic strength and stiffness formulae and later verified in ANSYS (figure 36). At the end the entire structure is modelled in Pro-E (see figure 37).

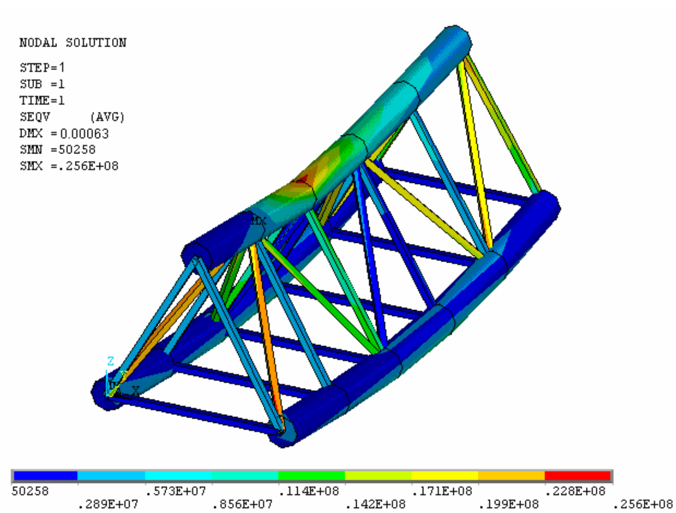

Figure 36 Ansys model of Support Structure

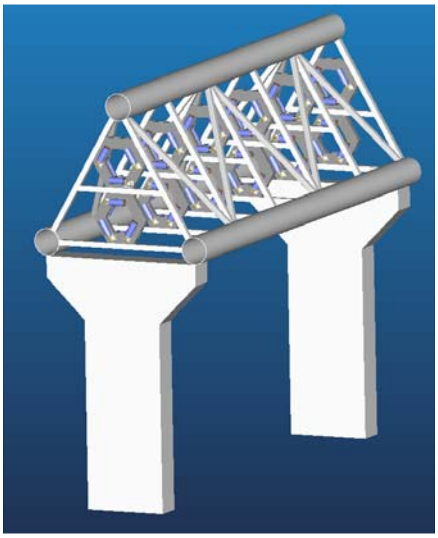

Figure 37 Pro-E model Support Structure

14 Sensor positioning, tooling and robot selection

Sensor positioning

The positioning of the laser vibrometer is delicate, because the entire maintenance system depends on the measurement results of this sensor. The measurement results of the laser-vibrometer will contain errors when:

1. The transversal amplitude in which the roll vibrates is too large; the laser must always be directed at the same point on the vibrating object in order to retrieve accurate results. A too large deflection (a) of the roll will give inaccurate speed measurements due transversal movement of the roll (see figure 38). When the deflection (a) is small, the transversal amplitude will also be small and will have no influence on the measurement result.
2. The frequency in which the laser-vibrometer vibrates is in the same frequency (in phase) as a bearing defect frequency; the vibrometer will then have difficulties to measure the amplitude of the defect in the bearing (see figure 39). In this case, the only possible way for the vibrometer to measure accurate; is when the <u>displacement amplitude of the laser vibrometer</u> is much smaller than the <u>displacement amplitude of the defect;</u> the amplitude difference is then large enough to be measured. For most structures this only achieved when there is sufficient damping or a vibro-isolator (or high-low-pass filter) is used.

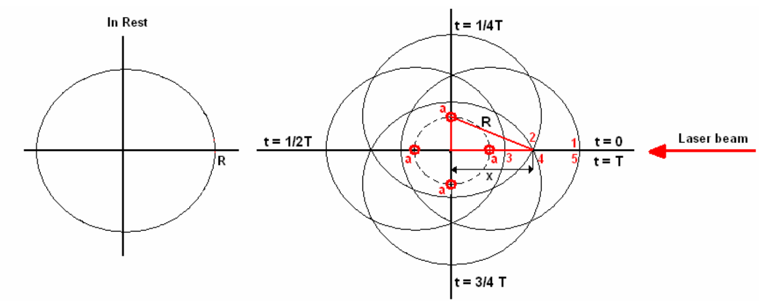

Figure 38 Roll vibration amplitudes for various time-units

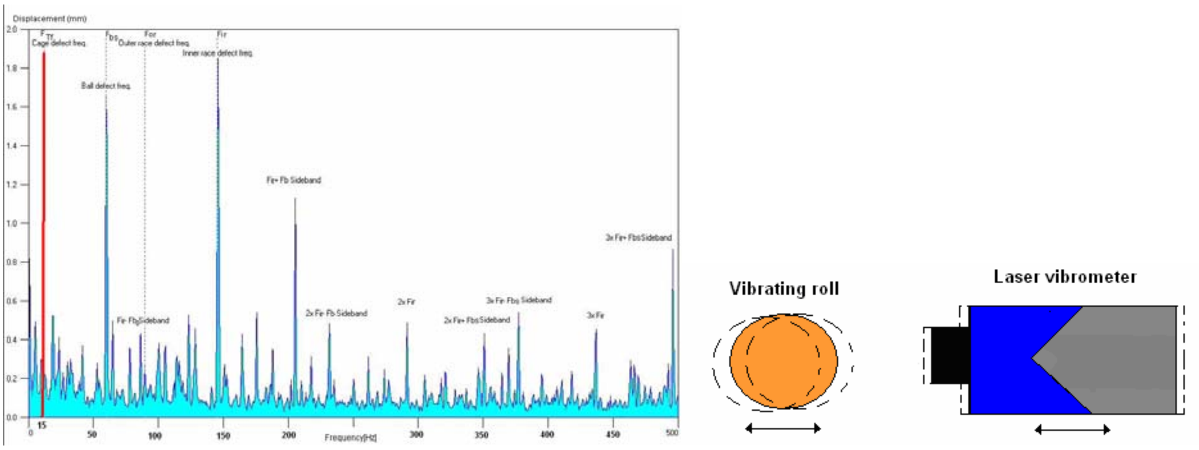

Figure 39 In phase vibration of laser vibro-meter with bearing defect frequency[14]

Excitation frequencies

There are three main excitation frequencies which cause transverse vibrations in the support structure:

1. Excitation frequency due geometric imperfections of idler rolls
2. Excitation frequency due large lump-sizes of material in belt (discontinuous bulk);
3. Rest vibration: excitation due start-stop motion of the trolley.

In real systems, some sort of damping or energy dissipation is always present; by simplifying the support structure of the pipe-conveyor as a single-degree-of freedom spring-mass-damper system, the response to harmonic excitation by the above described frequencies can be calculated. When there is no sufficient damping an appropriate vibration-isolator must be selected.
The effect of the excitation frequencies is determined, by calculating the maximum displacement amplitude for each excitation. Therefore the natural frequency derived from the ANSYS model is used (see figure 40).

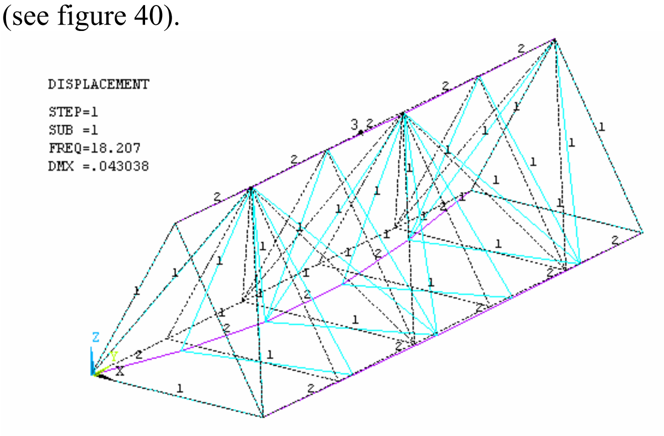

Figure 40 Vibration form lowest natural frequency

The following can be concluded from the results:

- From the calculations: the (un)balance frequency is in the range of the cage defect frequency; the laser vibrometer is therefore in phase with a defect frequency. Comparing the amplitude of the defect (0,2 mm) with the excitation amplitude of the system (0,02 mm) it can be concluded that the amplitude difference is large enough to be measured and there is sufficient damping in the system. Only for precaution a vibro-isolator needs to be installed.
- Also the calculated excitation amplitude due discontinuous bulk transport is very small, thus the damping of the system is sufficient. However for precaution a vibro-isolator can be used to completely minimize this vibration.

Standard vibro-isolators can be selected from the catalogue [15] by calculating the required spring stiffness. A cheaper solution is to use rubber-isolation plates [16] (see figure 41)

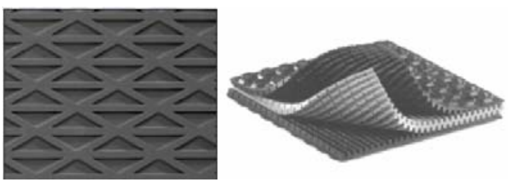

Figure 41 Rubber isolation plates from ERICS [16]

Note:
One must keep in mind that a vibration-isolator will minimize the excitation of the laser vibrometer, but will not completely remove the vibrations from the frequency spectrum. A high-low pass filter is needed to completely filter out the unnecessary frequencies (see figure 5).
The best way to measure each idler, is to place a vibrometer on each side of the trolley. The standard industrial laser-vibrometer from Polytec [14] (IVS-200)(figure 6), can't measure vibrations under a certain angle, however in combination with a beam deflector (VIB-A-100) measurements under angles up to 90 degrees is also possible (see figure 42):

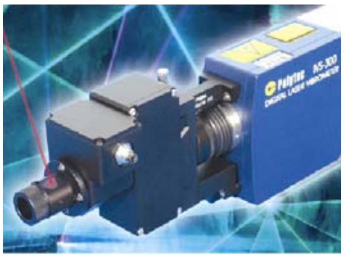

Figure 42 Beam deflector

Instrumentation is needed to operate the vibrometer; therefore a construction must be designed in which the instrumentation (and also the laser-vibrometer/ isolators) can be installed. See figure 43 for examples.

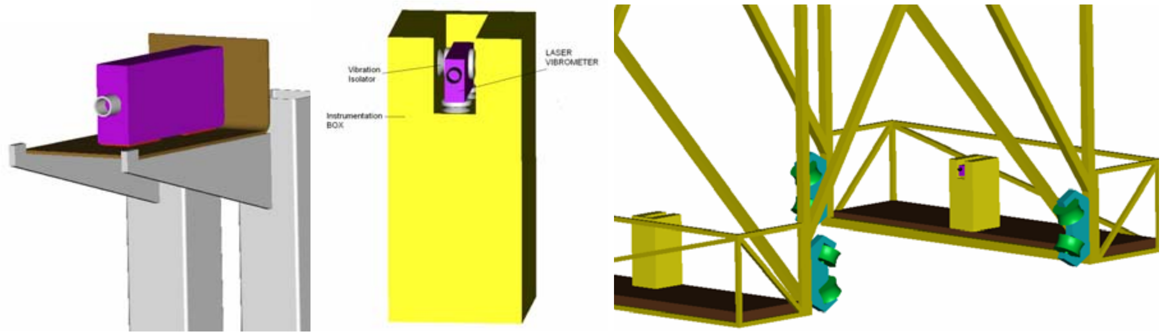

Figure 43 Positioning Laser vibrometer

Tooling for robot

Tooling is manipulated by the robot to perform the functions required for the application. Depending on the application, the robot may have several capabilities, in this case:

- lifting the belt
- (un)locking the idler-units.

Two concepts were designed see figure 8, however only concept 2 is suitable due the limited griping area of the new designed idler. The chosen concept is the product of two end-effectors (see figure 44).

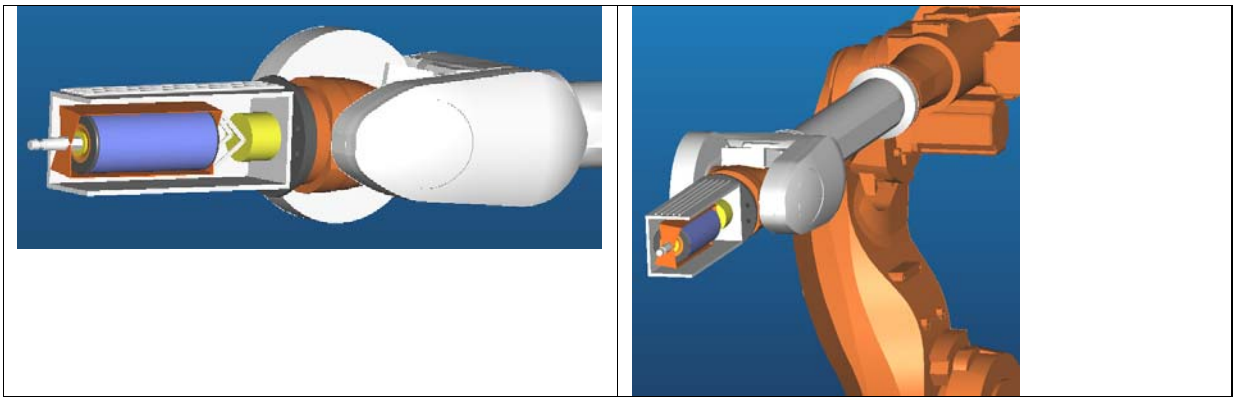

Figure 44 Concept for (re)placement idler-units

Description end-effector 1 (see figure 45)

1. A C-shaped profile is connected to the robot-arm, this offers the following advantages:

- The design of C-shape contains a large moment of inertia about its neutral axis. Therefore the shape is capable of carrying large loads without the use of excessive large wall thickness
- Also the open-end of the C-shape does not interfere with the gripping process of end-effector 2.
- On the C-shape, one or more rolls are positioned; these rolls will keep friction between the belt and end-effector as low as possible.

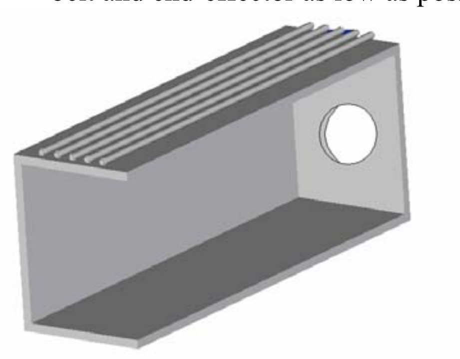

Figure 45 End-effector 1(C-shape)

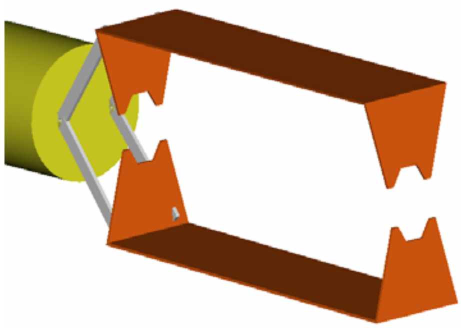

Figure 46 End-effector 2

Description end-effector 2 (see figure 46):

- This concept can be used in conjunction with end-effector 1.
- The idler-unit is grabbed by a gripper, the gripper has a rectangle shape with open sides (this is needed to approach the idler-units from the sides) (see figure 47).
- The gripper locks the hexagonal shape of the shaft with a hexagonal (or multiple) designed cut and finally rotates the idler-unit from the bracket.

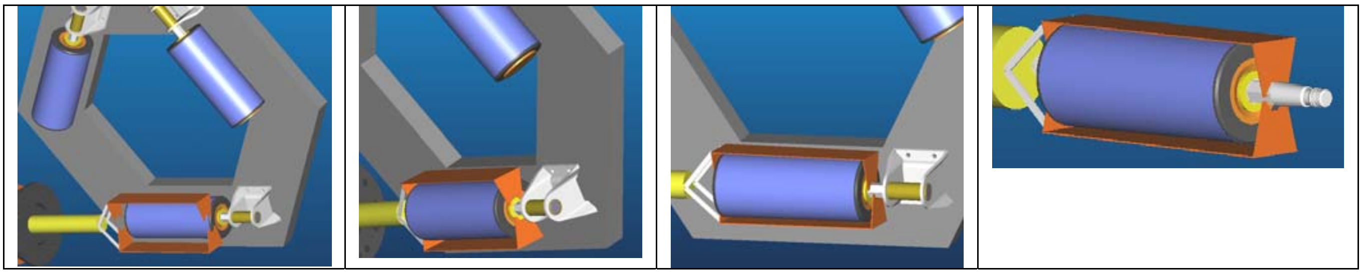

Figure 47 End-effector 2 locking procedure

Robot selection

Based on the required reach and payload an industrial robot can be selected from the catalogue. Earlier in the study the need of large payload was stated; to (re)place a damaged idler, the robot must first lift the belt and then (un)lock the idler from its position. The payload is then equal to the load on the idler. The maximum normal force on the lower centre idler is normative about 3000 N.
The minimal payload for the industrial robot is then equal to 300 kg.
To keep the replacement distance for one robot as low as possible, the robot should be positioned at the top of the structure (see figure 48). From the catalogue the KAWASAKi MX50 L is chosen.

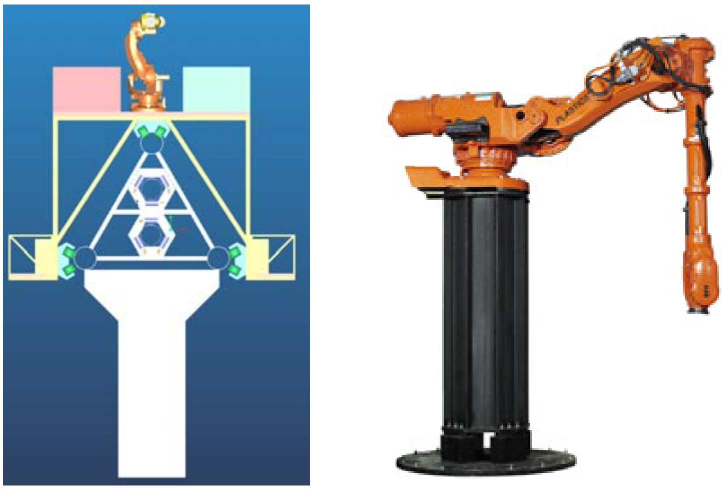

Figure 48 Positioning of robot on top of trolley

Note:
By using simulation software (for example ROBOTICS from ABB) it is possible to simulate the reach and therefore check the selected robot. If the duties are too difficult for one robot, an extra robot can be used. However for the understanding of the software is training required, and because the given limited time, this is left out as scope of this study and is given as recommendation. Fore now, it is presumed that one robot can (un)lock the idlers from the pipe-conveyor.

Box for damaged and new idlers

A box is needed to place new and damaged idlers. The lay-out of such a box is important for the replacement procedure; the idlers-units must be positioned in a way in which the robot can grab the unit on the hexagonal cut of the shaft. The most logical outcome is to incorporate some features of the idler bracket; the box must contain screw-threaded holes, in which the idler-units can be locked into (just like the (un)locking system of the idler). See figure 49 for a possible design of the box, multiple compartments are built-in for multiple idlers. For example when the needed space for the tooling and robot is 300 mm, 50 compartments can be placed in a 1500 x 1500 square box. Two boxes can be placed on the top of the trolley (see also figure 50):

1. Box 1 (red box) : Box for damaged idlers
2. Box 2 (green box): Box for new idlers.

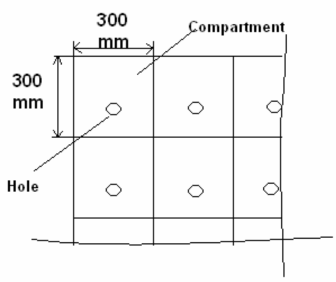

***Figure 49 Box wit compartments for placing new or defected idlers*.**

Trolley-lay out

The lay-out of the trolley largely depends on the positioning of:

- The robot;
- Robot sub-systems; control system
- 'Put-a-way box' for damaged idlers and/or new idlers.

See figure 50 for a possible lay-out of the trolley. All the important devices for replacement are set next to the robot (boxes for new and damaged idlers and control system). The roof of the trolley is adjusted; a hole is cut so that the robot can reach the idlers in the support structure.

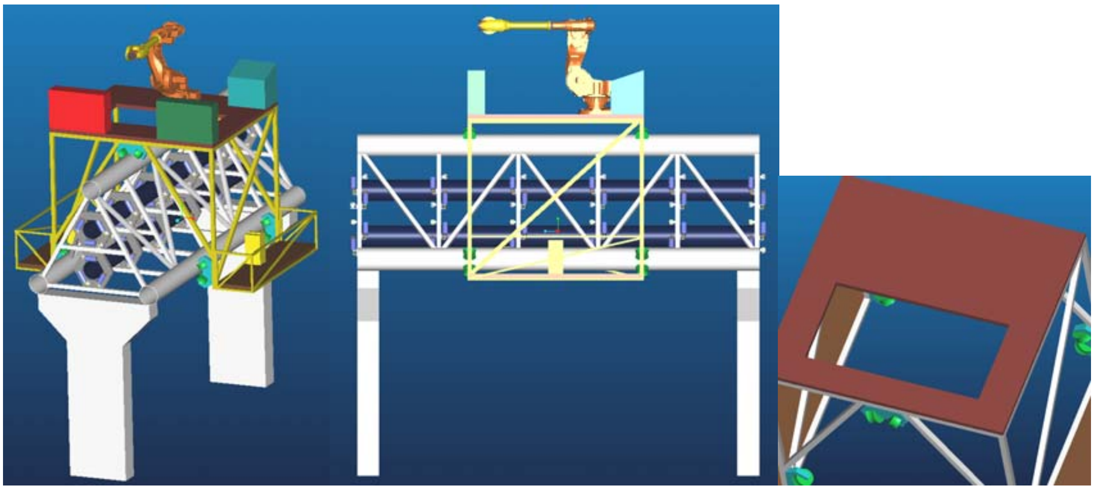

Figure 50 Lay-out on top of trolley

15 Cost calculations

The initial costs for the automated maintenance system are large. The system is beneficial after some years, before installing a large amount of money-investment is required. See figure 51 for a cost comparison between the automation maintenance and maintenance with external personal, where the R.O.I. is calculated; after approximately 9 years the total investment of the system can be recollected.

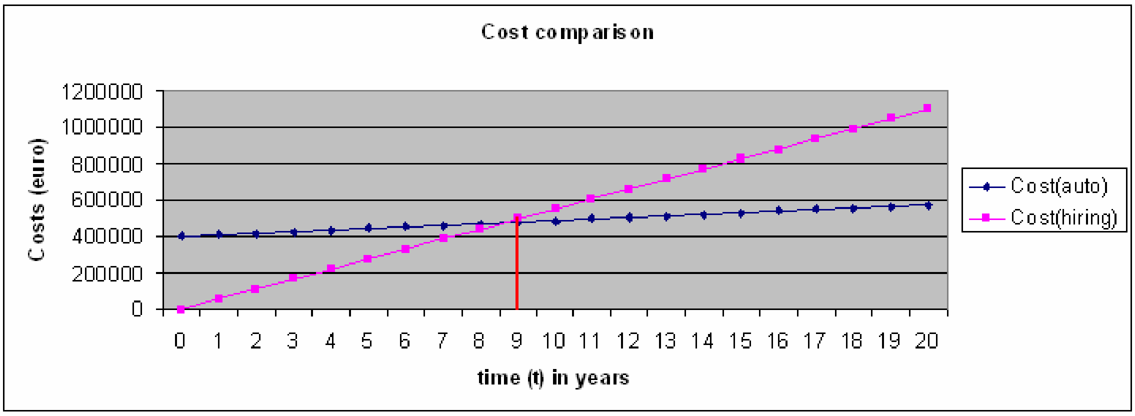

Figure 51 Cost comparison between automation of maintenance and hiring of personnel

16 Final Conclusions and Recommendations

At the end of this study a total automated maintenance concept for the pipe-conveyor is designed, with has the following advantages:

- No external maintenance personnel are needed to (re)place damaged and new idlers.
- The new designed idlers are light weighted and consists easily replaceable parts. Some of the parts are standard and can be bought from manufacturers of standard idlers. Also the idlers components can be used for various pipe-belt-diameters, by just increasing the length of the roll-shell.
- The system is in economical point of view advantageous over hiring external personal for maintenance. The R.O.I. point is about 9 years.
- Safety level of the system is increased, with the use of robots for replacing the idlers in dangerous/hazardous environments.
- This report does consist detailed calculations, which can be used for further pipe-conveyor belt developments and optimalisations.

Recommendations:

- It was concluded, that an IR-thermometer can be used as verification tool of the laser-vibrometer. It can for example be installed at the end of the robot-arm; further installation possibilities need to be investigated.
- The effect of wind on the vibrations of the support structure must be investigated.
- The applicability of the laser vibrometer and vibration-isolator must be investigated and questions must be answered like;
  - Are the results reliable enough for predictive maintenance purposes?
  - Has the chosen material type of the roller-shell (ABS) influence on the measurement results of the laser-vibrometer? For the measurement to be accurate the material has to be non-reflective.
  - How are the measurements results of the laser under difficult environment circumstances, like bad weather conditions, dusty environments?
  - Which unnecessary frequencies are ought to be filtered when high-low pass filter is used?
- The basic design of the tooling of the robot must be further investigated; industrial robot manufacturers must be contacted for the development of the tooling.
- The training idler must be automated to have a fully automated pipe-conveyor. The automation process, needed sensors and components are yet to be determined.
- The compression effects of lifting the belt by the tooling of the robot-arm must be investigated. A finite element model in ANSYS of the pipe-belt with the different load cases can give outcome on this matter.
- Further investigations in possibilities of using standard idlers for the automation process, for example integrating cantilevers for (re)placing the idlers by a robot.
- Future structure possibilities (like HORAK [13]); is it possible to use less idlers to compress the pipe-belt in a circular shape?

17 References

[1] Lodewijks, G., Strategies for Automated Maintenance, Faculty of Design, Engineering and Production, Delft University of technology, papers, 2005-2006, http://www.pipeconveyor.com/
[2] Walien, K.H. (2002), 'Onderhoudstrategie van een onderhoudsrobot voor bandtransporteurs', Report number 2002.LT.5602, Delft University of Technology, the Netherlands
[3] Koenis, R.E.M. (2002), 'Simulatie onderhoudsrobot voor een bandtransporteur', report number 2002.LT.5668, Delft University of Technology, the Netherlands
[4] CEMA (Conveyor Equipment Manufacturers Association), Belt Conveyors for Bulk Materials, Washington, 1966.
[5] Loeffler, F.J., Pipe/tube Conveyors -A modern method of bulk materials transport, USA, Bulk Solids Handling, Vol.20, number 4, October/December 2000
[6] Behrens, U., Untersuchungen zum Walkwiderstand schwerer Förderbandanlagen Braunkohle Wärme und Energie, 7, 1968
[7] Lodewijks, G., Dynamics of Belt systems, 1997
[8] Wesemeier, M.,Theoretische Untersuchungen zur Schlauchformkraft am Schlauchgurtsteilförderer, Schüttgut 3, nr.1, 1997.
[9] SKF-Bearing experts, 2005-2006, http://www.skf.com/
[10] Ashby, M., Materials Selection in Mechanical Design, Oxford, third edition, 2005.
[11] Inman, D.J., Engineering Vibration, Prentice Hall Inc, second edition, 1996.
[12] Clifford Mathews, Engineers'Guide to Rotating equipment, London and Bury St Edmunds, UK, 2002
[13] Horak, R.M., Improved Idler Panel Design for Pipe Conveyors, Bulk Solids Handling, volume 17, number 4, October/December 1997.
[14] Polytec, 2005-2006, www.polytec.com.
[15] VIBROSTOP, 2005-2006, http://www.vibrostop.it/
[16] ERIKS B.V., postbus 280, Alkmaar, Eriks-cd rom (2006).