ANALYSIS OF BELT STRESSES IN THE IDLER JUNCTION AREA

PART 1: RIG CONSTRUCTION AND CALIBRATION

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ABSTRACT

This research report describes the creation of a unique experimental facility for investigating localised stresses that can develop in conveyor belting during operation. High localised stresses can cause premature failure of conveyor belts, requiring expensive replacement. A key objective of carrying out research in this field is to gain a fundamental understanding of the stress that develops in various types of conveyor belting as it crosses over idler rollers. An experimental facility was developed which will be able to measure the stress and the deformation for different types of belting, such as solid woven/PVC and ply belting, in different belt classes. Particular attention was given to the various effects at the junction point caused by different idler configurations.

Idler arrangements are configurable in the 24 metre-long test facility for inline, offset and belt-friendly types. Belt stresses at the idler junctions of these configurations are measured by applying strain gauges and load cells. The offset distance can be varied to determine the effect this has on the developing idler junction stress. This allows comparison of the stresses as the class of belt increases for each type of belt. The value of doing so is to determine the effect that the weft strength or stiffness has as the belt is forced into the idler junction.

The test facility which was designed and built was shown to meet the requirements of the project. The instruments were calibrated to an acceptable uncertainty. The test facility can handle the full range of planned tests in terms of the design strength and is modular enough to handle a variety of other research initiatives. The establishment of a large, specialised experimental facility constitutes the first phase of an ongoing research programme into improving the design standards for belt conveyor systems.

INTRODUCTION

Conveyors are the arteries of the bulk materials handling industry, moving large amounts of material from the source point to its destination. The basic components of a conveyor are the idlers, conveyor belt, pulleys and drives. The most important component, because of its relatively high cost and wear rate, is the belt itself.

The conveyor belt is subjected to different dynamic loading actions as it rides loaded on the carrying idler rolls in the one direction and unloaded on the return idler rolls in the other direction. The interaction between the conveyor belt and the idler rolls is therefore extremely important as the idler rolls come into contact with the belt most frequently.

PURPOSE OF THE STUDY

The aim of this investigation is to attempt to better understand the stresses occurring within the conveyor belt, in particular in the idler junction area. How do the various idler configurations impart stress into this area and which configuration would impart the least stress?

The fact that despite a long history of development of design theories, designers still need to apply the accepted safety factors of 10 for fabric belts and 6.67 for steel cord belts. This reveals that there remains scope for improvement in the field of conveyor design.

By gaining a greater understanding of the dynamic forces acting on a conveyor, it is possible to design idler configurations which reduce the stresses in conveyor belting. This in turn allows conveyor designers to reduce the class of conveyor belt for a particular application, thereby offering the industry considerable savings, not only in capital but also in the operational cost over the life of a conveyor belt.

RESEARCH BACKGROUND

The debate in the bulk materials handling industry on whether offset idlers are 'gentler' on the belt compared to inline idlers has raged for many years. This debate was exacerbated by the introduction of the so called 'belt friendly idler' which has an even greater offset between the rolls than the conventional offset idler, as noted in the national standard (SANS 1313-1, 2012).

Damage and delamination of the conveyor belt layers is on the rise (Pitcher, 2015) and an emerging trend in the industry is that this increase in belt damage is thought to be related to the dynamic action occurring at the junction between idler rolls. Of the single roll, two-roll vee, three-roll and five-roll carrying idler configurations being used in the industry, the three-roll idler configuration is by far the most common.

In the carrying idler designs, there are three methods of arranging the idler rolls in relation to the cross member. This research focuses on the three configurations:

1. Inline

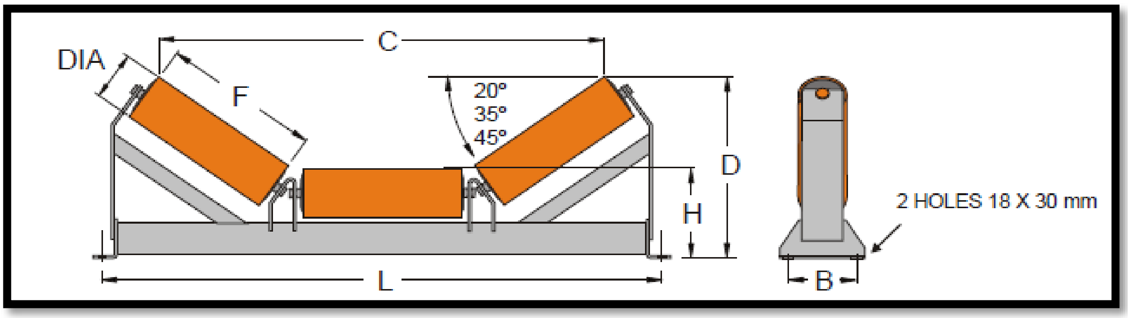

Figure 1. Three-roll inline troughing idler.

As the name suggests, the three rolls are arranged in a troughing configuration (at the desired angle) with the rolls being inline, as can be seen in the side view of the above illustration.

2. Offset

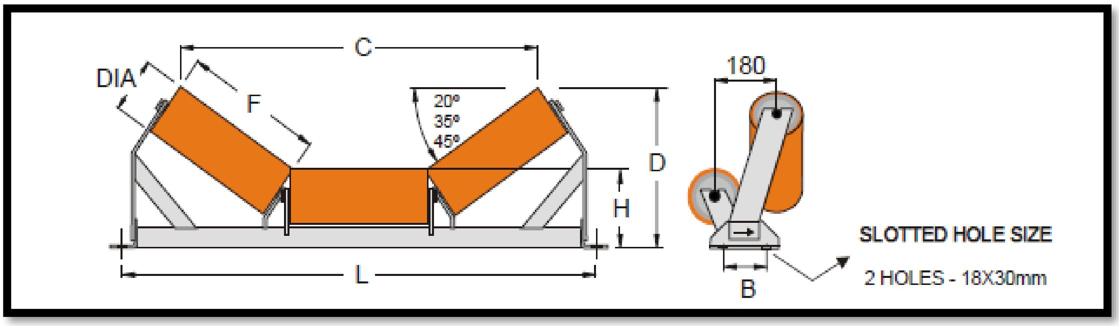

Figure 2. Three-roll offset troughing idler.

In the offset configuration, the centre roll is offset relative to the wing rolls. The offset distance is governed in South Africa by the SANS 1313-1 standard, which stipulates that: '*the horizontal distance between the axis of the centre roll and the axis of an offset roll, when the rolls are aligned parallel to each other, shall, subject to a tolerance of +5mm be as follows:*

a. *150mm in the case of idlers the nominal diameter of which is less than or equal to 150mm, and*
b. *180mm in the case of idlers the nominal diameter of which exceeds 150mm."* (SANS 1313-1, 2012)

3. Offset Belt-friendly

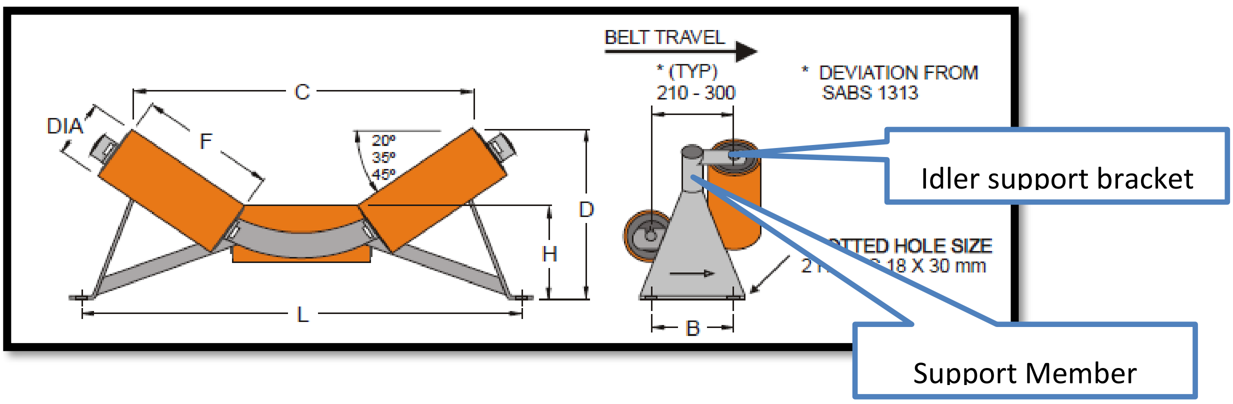

Figure 3. Roll offset belt-friendly troughing idler.

The offset distance in the 'belt-friendly' configuration, as shown above, is greater than that of the standard offset idler because the diameter of the cross member is included in the offset distance.

The concept of the belt-friendly idler is that if the centre roll failed and dislodged, then the cross member would effectively carry the belt across the full length of where the roll is supposed to be, preventing the roller retention brackets from cutting into the belt, as would occur on a conventional offset idler.

It is important to note that there is no documented historical data to support the supposition that this mode of belt damage is a major threat or cost to the industry.

RESEARCH MOTIVATION

The primary purpose of this investigation is to determine the influence on the stress in the belting with respect to the positioning of the support rollers for the configurations mentioned above.

Specifically, what the distance between the centre roll and the wing roll should be to optimise the performance of a conveyor belt and does that distance vary with the type of conveyor belt employed for a particular application (Figure 4)?

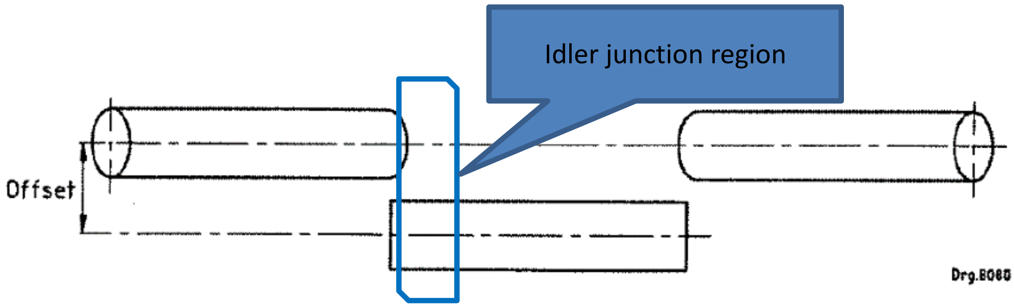

Figure 4. Illustration of offset distance (SANS 1313-1, 2012).

As the focus of the study is on determining which of the idler configurations has the least effect in terms of stress within the belt, comparing the range of idlers from inline to various distances between centre lines of offset, only three roll idler configurations are evaluated.

RESEARCH OBJECTIVES AND SCOPE

The goal of this research is to set up the foundation for a truly comprehensive model that can help conveyor designers, and afford conveyor maintenance operators the knowledge and insight into the best choice of idler configuration for a given conveyor belt, in order to maximise the belt life by reducing stress.

The problem identified is that the stress which develops as the belt passes over the idlers is not yet clearly understood. This study attempts to define the different stresses developed on the most commonly utilised idler configurations in South Africa. i.e. three-roll inline, offset and belt-friendly idlers.

In order for factual information to be compiled, data needs to be collected for analysis. To this end, a comprehensive test facility was constructed, complete with sensing and measuring instruments to make interpretable data available.

It was important that the integrity of the data not be compromised by the design and construction of the test facility, and reflect a true application despite numerous constraints such as cost, complexity and limitations on current instrumentation.

Further consideration was given to understanding how the selected instruments function to obtain maximum value in terms of the quality of data.

The research has three definitive phases:

1. Design and manufacture of the test facility, and validation that the design meets the desired outcomes. This is the subject of this research report.
2. Running the tests to capture the data and finally, the conversion of the data into information.
3. Comparison with the results obtained from FEA modelling. Ideally, the comparison will validate the FEA studies, resulting in high levels of confidence in the use of FEA modelling applied to other belt widths and idler configurations.

This research report covers the first aspect of the entire research scope (which is Phase 1 mentioned above) while further studies will be conducted to complete the next two phases.

ASSUMPTIONS MADE

Certain assumptions were made to simplify the test parameters and guide the design. The most pertinent are listed below:

1. The operating range of the conveyor belting is in the linear region. The strain is linearly proportional to the stress in the test operating conditions.
2. These configurations are evaluated in terms of load with different types of conveyor belting, namely fabric and solid woven. Other factors such as roll diameter and the type of roll (polymer or steel) are assumed to not have any tangible effect on the evaluation and are thus be ignored.
3. The influence of weft strength or stiffness on the results is offset by the selection of a high, middle of the range and low class belt, for each type of belt. Steel cord belting is not included in this research as delamination does not occur between the cords and the rubber filler material. A probable reason for this is that the carcass is made of cords and surrounded by rubber, which can withstand a large amount of elongation, therefore, the carcass cannot crease, and over time fatigue occurs, followed by delamination.

DESIGN AND DEVELOPMENT OF THE EXPERIMENTAL TEST FACILITY

To achieve the objectives of this project, construction of the test facility had to fulfil certain requirements. Of importance was the ability to measure stress in the belt, particularly in the idler junction region. Historical data reveals that the highest levels of failure occur on convex curves (Pitcher, 2015). Thus, the test developed for this study is in the form of a convex curve. Note that regardless of the relative loading on a belt, the idler junction pressure is accentuated on a convex curve.

The test facility should allow for repeatable test measurements, and the various test parameters should be easily adjustable. Important test parameters include the testing of various trough angles. A modular design facilitates testing beyond the scope of this project. Design features should include the ability to handle loads and operate safely.

The above should be achieved while considering certain constraints. The first and foremost was cost, this would shape which test instrumentation could be selected and the overall design of the test facility. There were also the limitations of the sponsors, in terms of their technical capabilities and what they could provide in a certain time frame. Another major factor having a bearing on the design was the space available for the construction of the test facility and the resources needed to erect it.

THE OPERATION OF THE EXPERIMENTAL FACILITY

The labels 'a' to 'n' describe the major components of the test facility, shown in Figure 5.

The belt is tensioned via the hydraulic puller (a) which runs on rails (l). The rails allow for the belt to move a distance of up to 1.5 m. An important step is to create movement over the extent of the area. The measuring equipment is positioned to coincide with the area which is at the centre of the structure.

The belt moves through the area collecting data. Most pertinent is the area preceding the junction, through the idler junction and beyond.

The tension is transmitted through the steel wire cable (j) and around the sheave wheels (d). The sheave structure (d) houses two sheaves, the larger sheave is the load-bearing element while the smaller sheave is there to direct the cable tension.

The cables carry a maximum load of 20 tonnes, therefore the sheave frame holder (m) needs to be able to withstand a load in the order of 40 tonnes. The sheave frame holder is embedded into a cube of concrete with the dimension of 1 200 mm length per side. The soil conditions were soft and unstable, thus to accommodate the soil condition a larger area was excavated. The concrete was reinforced and braced with steel members.

The cable is connected to a shackle of the belt attachment (k). The adjustable belt attachment allows for the belt to be troughed from zero to 90 degrees. This design reduces time for the various setups as the trough angle is increased from 0 degrees.

In the initial design concept, a pulley was proposed. Therefore, the belt would be carried on the idlers and then be pulled around the pulleys and the two belt ends would be tensioned after that. This idea posed two major challenges:

1. The strain gauges could not tolerate the strain of going around the pulleys in a continuous cycle. This might exceed the maximum strain limit of the gauges and each successive cycle of the belt would yield a different strain value for the same load.
2. The second hurdle was to accommodate the transition distance to normalise the stress (change of the trough shape from a flat belt to having a trough angle of up to 90 degrees). This would increase the length of the test facility dramatically. (All

the equipment had to be built under cover due to the sensitive electric equipment).

Thus, the belt attachment and sheaves were designed to overcome these challenges. As shown in Figure 5 and Figure 7, the steel wire rope is threaded around the pulleys which and also connected to the belt attachment. Figure 7 shows a close-up view of the belt attachment which is set at 35 degrees.

Figure 5. Image of the sheave structure and belt attachment.

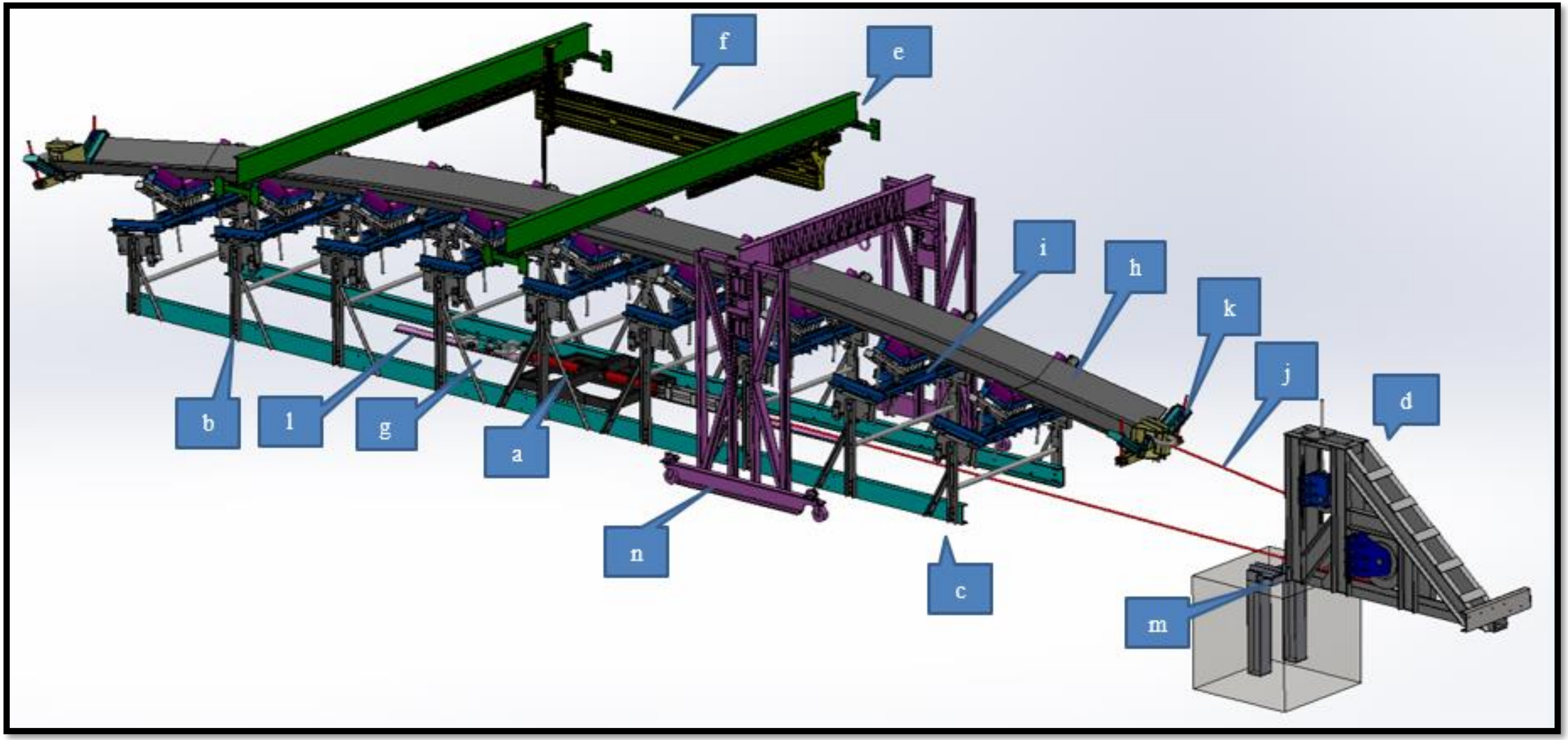

Figure 6. Components of the test facility.

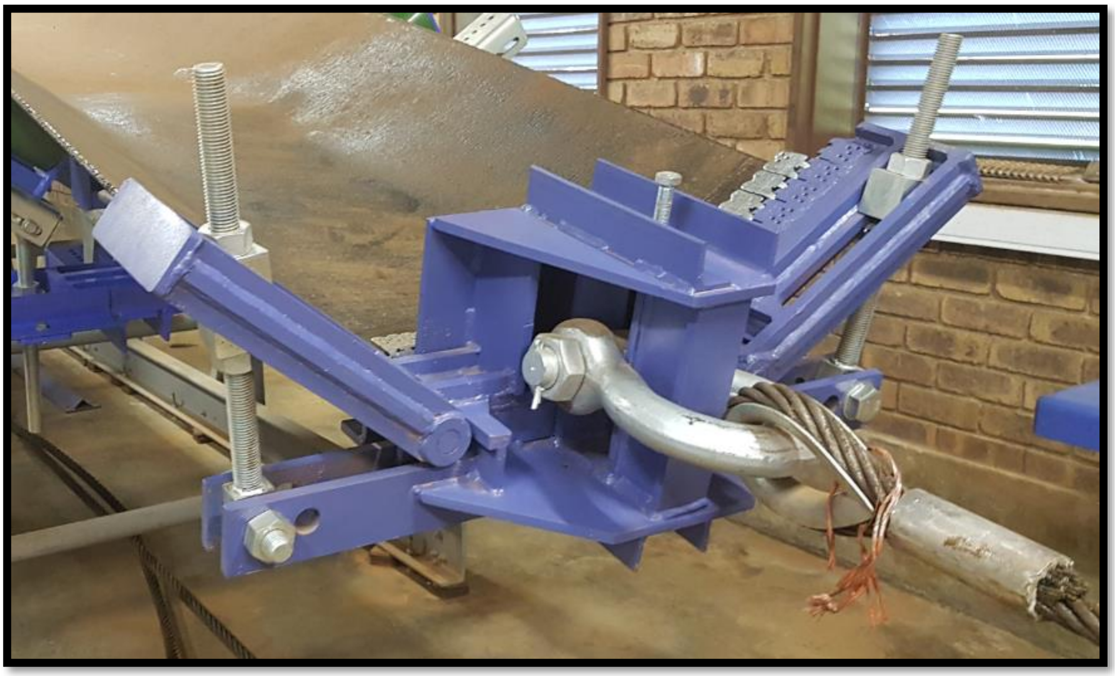

Figure 7. Belt attachment in operation.

The belt attachment allows for the tension from the wire rope to be distributed into the belt (h). The belt is set at a radius of 35 m on a convex curve. The belt is connected to the belt attachment via a mechanical splice.

The length of the testing facility and the maintenance of the troughed shape was viewed as of the utmost importance to eliminate the stress effects of the transition distance. The transition induces additional stress and so the added length of the three idlers on each side of the three centre idlers, where all the measurement would take place, was included to circumvent this issue or at least to lessen its effects.

The belt is supported by the universal idler frames (i), which rest on the column supports and support base (b). The column supports bolt directly into the base frame and allow for easy repeatable and accurate assembly.

The universal idler frames are versatile in their design. The trough angle can be varied from 0 to 90 degrees with a simple jacking bolt arrangement. The offset distance can reach a maximum of 450 mm, while the wing rolls can be set at up to 5 degrees of forward tilt. The universal idlers are designed to be very strong and rigid structures to minimise deflection and accommodate large moment loads generated by the offset.

The overhead structure (e) provides the mounting for the belt profiler (f). The overhead frame needs to have negligible deflection and as such, a deep I beam section was chosen. As the name suggests, the belt profiler moves in three orthogonal directions and is able to map the profile of the belt. There are three magnetic encoders used for the linear measurement along each axis (Figure 8). The probe of the belt profiler comes into contact with the belt and is moved across the weft direction of the belt a predefined distance so that a comparison of the different types of belts is obtained.

The belt profiler uses magnetic encoders which provide precise repeatable results without any calibration required. The belt profiler caters for the variation from the highest point in the belt trough to the lowest point.

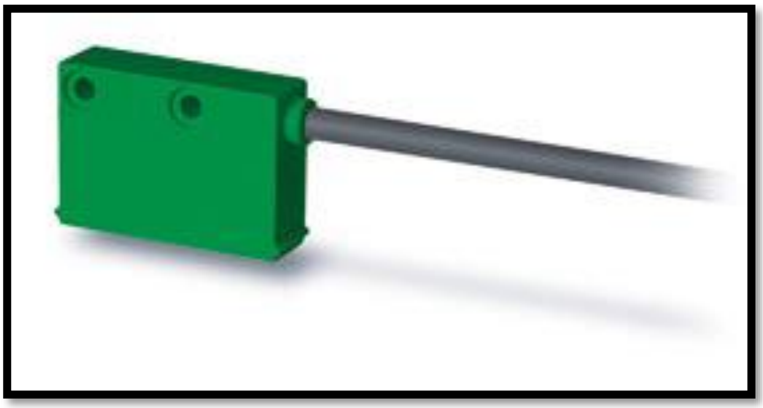

Figure 8. Magnetic encoder used on the testing facility.

There are various load cells placed on the testing facility to capture the necessary data. A tensile load cell (g) measures the tension applied to the steel wire cable. Under the idler frames, compression load cells are placed to measure the force being applied from the belt, the convex curve and material that is loaded onto the belt.

The stress within the belt is measured by means of strain gauges applied directly to the belt. The provision for the belt to move over the idlers is essential as it allows for the belt to move from a stress zone prior to the idler junction, past the idler junction zone, to the zone after the idler junction. It is important to ascertain whether there is a stress change from before to after the idler junction and the distance that it takes to normalise the stress in the belt after the idler junction (Figure 9). The RTDs (resistance temperature detectors) (PT100) measure the temperature on the top and bottom belt cover and that of the ambient temperature of the test facility.

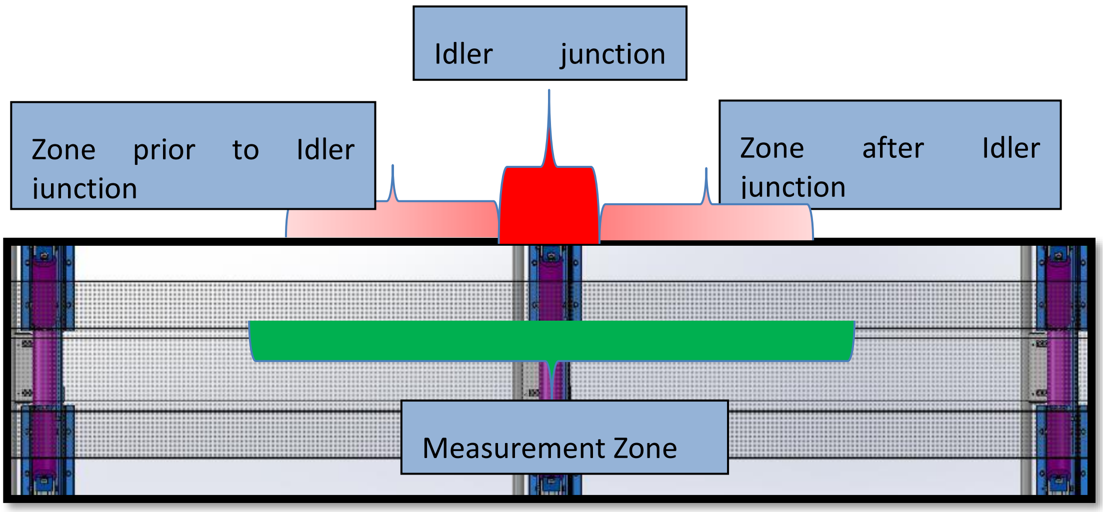

Figure 9. Illustration of important zones in the test setup, top view.

There are two distinct setup options available, each with a specific purpose. Figure 10 illustrates the straight setup option in dimetric view while Figure 11 shows a front view of the setup. This indicates that there may be five rows of idlers, which can also be varied to four rows of idlers. The value of varying the number of idler supports is to determine the effect of sag tension on the idler junction, effectively noting the effect of idler spacing.

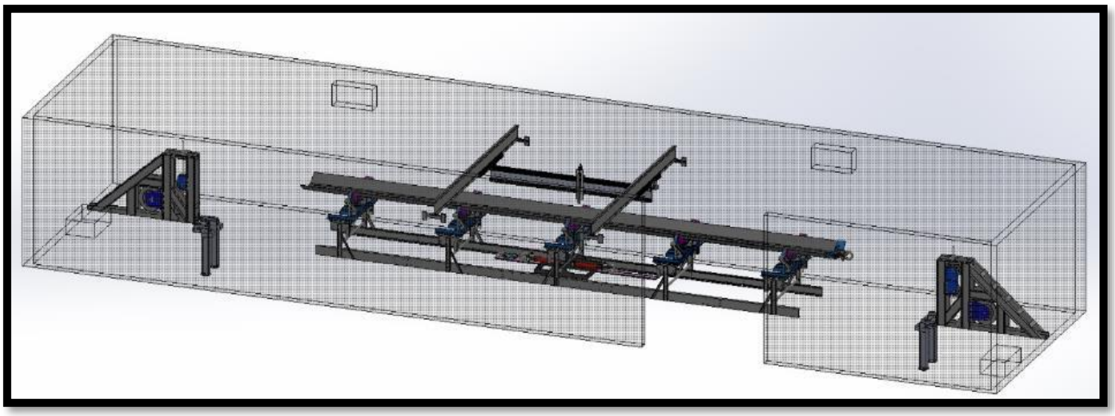

Figure 10. Experimental facility depicting the straight setup, dimetric view.

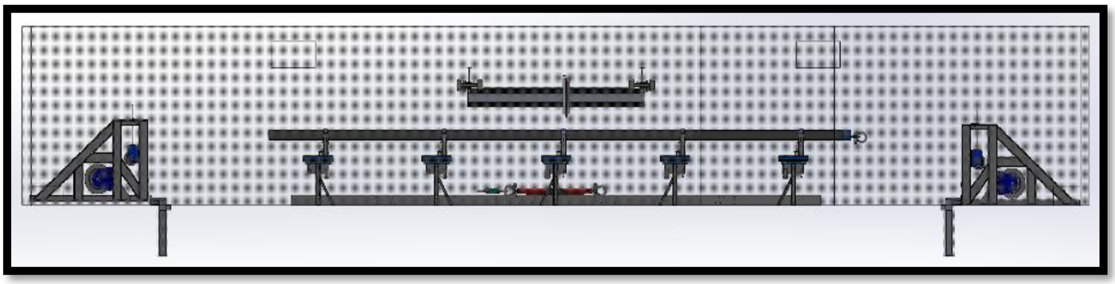

Figure 11. Experimental facility depicting the straight setup, front view.

Figure 12 and Figure 13 illustrate the convex setup. The convex setup exacerbates the stress in the junction region. This is as a result of the additional loading that is experienced by the idlers due to the curvature of the belt.

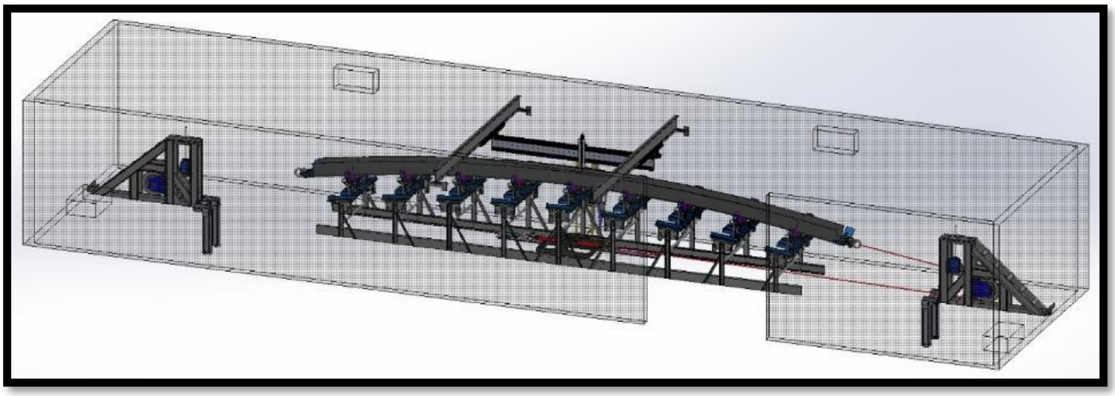

Figure 12. Experimental facility depicting the convex setup, dimetric view.

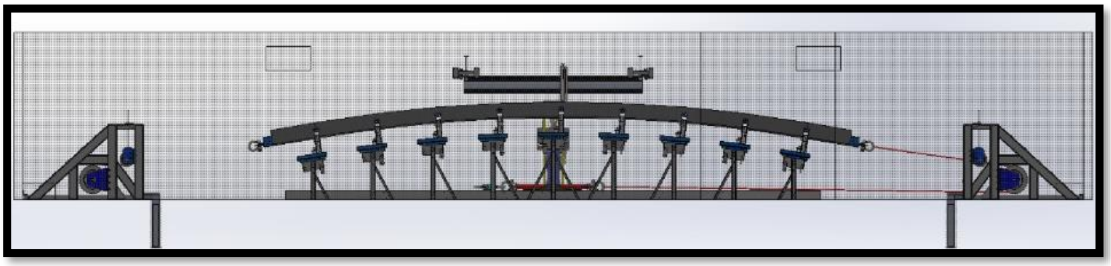

Figure 13. Experimental facility depicting the convex setup, front view.

The support structure was designed to hold the idlers (idler roll and idler base), the load due to the convex curve, and the mass of the belt and the material (if present). The belt is maintained in the trough configuration to reduce the stresses that are induced as a result of the transition distance from where the belt changes from its troughed state to the flat state as it goes around a pulley.

The troughed state is maintained by means of a section of steel, the belt attachment, that has its geometry adjusted to conform to the trough of the belt. The belt attachment is then connected to a steel rope to which the load is applied.

The belt gantry lifter (n) is used to lift the belt under tension. This allows the universal idlers' trough angle and forward tilt to be adjusted without removing the tension.

EXPERIMENTAL PROGRAMME

Due to the large number of testing parameters, as tabulated in Table 1, a systematic procedure needs to be conducted to expedite the process. The programme will commence after this research project has proved that the test facility is capable of performing the tests as outlined below.

Each type of belt being tested, PVC and ply, will have the trough angle varied in increments of 15 degrees starting at zero and ending at 90 degrees. For every trough angle the offset distance of the centre roll will be varied in 25 mm steps to a maximum of 450 mm. The forward tilt of the wing rollers can also be varied in discrete values of 0, 2 or 5 degrees. The loading on the belt, through the hydraulic puller, can also be varied but may not exceed the strain limit of the strain gauge.

The stress will be measured at key points along the conveyor (Figure 14). These points are at the belt edge (1) and the centre of the belt (5). This will allow a comparison of the calculated stresses at these points to measured stresses. Other areas of interest will be at the centre of the wing roller (2) so that the stress distribution can be more accurately quantified, immediately preceding (3), immediately after (4) and in the idler junction (6). Location (7) represents a string of strain gauges so that the maximum or peak stress can be accurately located.

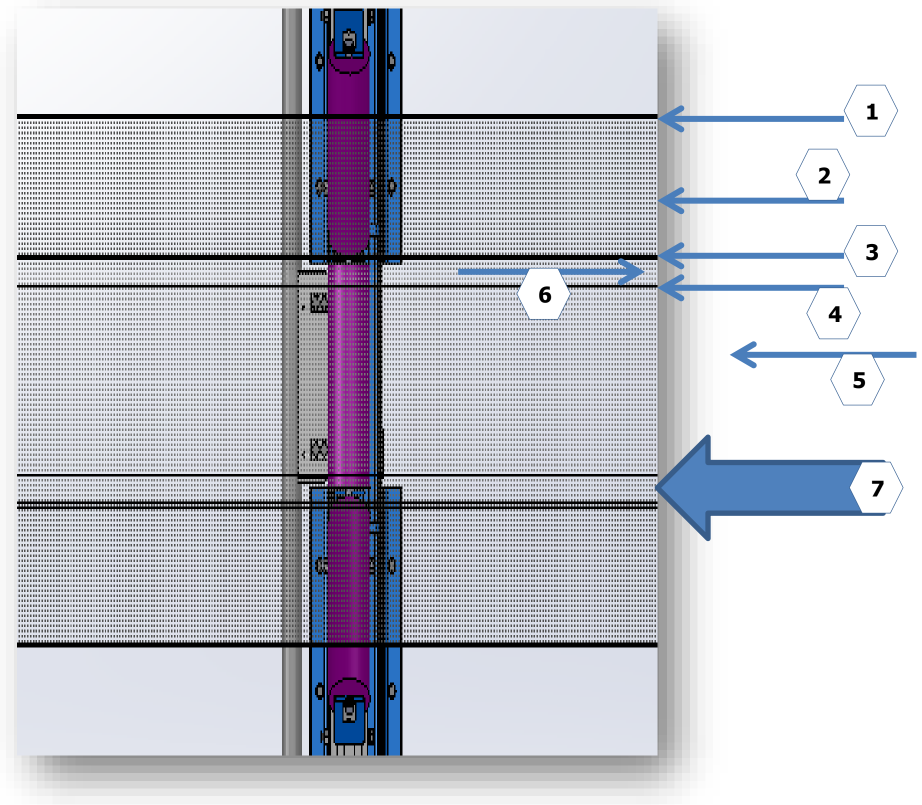

Figure 14. Location for stress measurement, top view.

Table **1** below illustrates the presentation of data that would be expected from the test facility.

Belt	**Forward Tilt**	**Trough Angle**	**Offset**	**Load %**	**Stress 1...n**	**Load Cell 1…k**	**Encoder 1..3**
Belt 1…6	0-5 Deg	0-90 Deg	0-450 mm	80-100%	xxx	xxx	xxx

Table 1. Layout of data to be collected from test facility.

CALIBRATION

The calibration process is of utmost importance to ensure reliable and accurate output of results. Calibration and validation work was undertaken to ensure that the results obtained are accurate and repeatable.

The DAQ equipment was utilised during the calibration process, making it easy to apply the correct scaling of the live readings during testing. The major components calibrated were:

1. The load cells. The load cells were calibrated from an initial state to the maximum state.
    a. Two tonne load cells
    b. Twenty tonne load cells
2. Strain gauges on belting.
    c. Strain gauges were attached to the belting in the warp and weft directions. Tests will be conducted to determine if stress on the surface of the belt is similar to that in the carcass (validation of the assumption that the stress does not vary through the thickness of the belt, i.e. the carcass and covers see the same stress and strain).
3. The magnetic encoders are a digital system and as such do not require any form of calibration.

RANGE AND SCOPE OF THE TEST FACILITY

The test facility is flexible in a variety of ways; it can handle many different experiments. This report outlines one particular research application for the test facility. However, the versatile design allows for other projects to be conducted. Some of the range of tests that could be carried out are:

1. Idler junction testing on SANS standard 1050 belt width (which is the focus of this design project).
2. Investigation of transition normalisation distance.
3. The test facility can accommodate idler roll length variations where the wing and the centre rolls can be of different lengths and diameters.
    a. The centre roll may be longer with a larger diameter and bearings to accommodate a higher load.
    b. Idler junction stress with different wing and centre roll dimensions.
    c. Does the roll diameter have an effect on the magnitude of the stress? In other words, would a larger roll diameter have a lower stress impact due to the larger contact area?
4. The effect of misalignment of the idlers can be more accurately quantified.
5. Different types of idler rolls can be used to determine stress effects; steel versus polymer rollers.
6. Determining the ideal idler junction gap and whether the gaps given in SANS 1313 specifications are appropriate.
7. Looking at the effect of pressure on the idler face with and without idler forward tilt.
8. Should the centre roll be leading or trailing? The force imparted into a belt may give an indication of tracking ability. This would determine if the centre roll should be leading or trailing in terms of the effect of stress experienced by the belt.

9. Look at friction factors between various troughing angles, is there a relationship between trough angle and friction factor?

NEXT STEPS

Once the following work items have been completed, full scale tests can commence.

1. Continue with the belt sample testing, in order to fully understand which size of gauge is most suitable (5 mm or 10 mm gauge). Also, which type of adhesive, a polymer (SC2000) or a cyanoacrylate (super glue) would yield the most consistent results?
2. Understand more thoroughly the stress variation across the belt sample and across the various sample pieces.
3. Consider the use of DIC (digital image correlation) techniques in order to understand how the entire belt sample experiences strain; does it vary across and along the belt sample?
4. Due to the large number of tests, it would be ideal to refine current measurement methods to more easily obtain data and convert the data into useful information, such as separating loading and unloading cycles to better extrapolate data to find better ways of obtaining trends which could be used in full scale testing.
5. Further investigate the ISO 9856 specification to determined how much permanent stretch is in a belt and how many cycles of testing are required in order to adequately remove this permanent stretch.

RECOMMENDATIONS FOR FURTHER WORK

This research report describes how the test facility has proven to be fit for its intended purpose. It can be used to measure strain, force, displacement and temperature. The items described in the section above are the immediate next steps that should be completed along with ensuring that the hydraulic system can deliver the 20 tonne output tension required and a system to move the belt and steel cables at a constant speed.

A full scale test programme with a straight and a convex configuration could be initiated. The straight configuration would have five idlers all in a straight line while the convex configuration would have nine idler frames in the shape of a convex curve. Various other parameters would be considered, such as the type of belt; ply or solid woven. There would be various strengths or classes of belt that would be tested. The various idler parameters would be tested, which would involve tilting the wing rollers forward and incrementing the trough angle in 15 degree increments.

The centre roll would be offset in increments of 25 mm up to a maximum of 450 mm and finally, the load could be varied up to 120% of the operating tension. A control experiment would be used as a basis for evaluation, which would be the 0 degree configuration. The belt would be formed into the trough shape as the trough angle is increased in set increments. The stress within the belt would be determined by measurement and compared with the results obtained from FEA modelling. Ideally the comparison would validate the FEA studies, resulting in high levels of confidence in the use of FEA modelling on other belt widths and idler configurations. It would be useful if meaningful results from the data could be drawn to conclude whether an optimal distance for the offset distance between the centre idler roll and the wing roll exists for a given configuration.

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