Conveyor Five (5) Roll Trough Idler Geometry Optimisation

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Synopsis

Australia is the world’s 5th largest coal producer* with total production at 527 million tonnes ** in 2012-2013 and the 2nd largest iron ore producer with total production 530 million tonnes in 2013*. The ongoing quest for reduced production cost, creates demand for more efficient materials handling solutions including conveyor design. The efficiency can be measured in terms of capacity per unit width and reliability of operation.

In Australian underground coal mines, there has been a preference in many maingate, trunk and some drift (slope) conveyor applications for 5 Roll trough idler geometry. The 5 Roll design is generally preferred because the idler lengths are shorter than they would otherwise be with equivalent 3 Roll structure and therefore lighter in weight and easier to handle particularly for 1800mm and greater belt widths.

The paper presents new information which differentiates and classifies three types of 5 Roll offset and inline trough idler geometry. The relationship between geometry and idler to belt contact length is explained and so is the resultant influence these geometry have on conveyor belt tracking performance with the same belt construction. As conveyor lengths and belt tensions increase, the belt carcass strength and stiffness also increases. The compatibility of belt and idler structure needs to be maintained by optimising the idler geometry for a successful outcome.

Optimised conveyor 5 Roll trough idler geometry examples in coal and iron ore mining applications are presented. Consideration of proper idler junction gaps to provide adequate support for the belt is also outlined.
1. Introduction

Mining companies are transitioning from high capital expenditure greenfield projects, to squeezing more out of the existing operations. On a couple of recent projects in Australia, 5 roll trough idlers have been used to reduce loading point maintenance and substantially increase conveyor capacity (Refs. #4,#5). Depending on the ore properties, 5 roll trough idlers can increase capacity by up to 40%.

This paper has been written to outline the relative influence of 5 roll trough idler geometry design on conveyor capacity and belt support. Belt support has a direct effect on both belt life and belt tracking performance. Information presented has been gathered over the last 10 years from a combination of studies into belt transverse flexural stiffness, troughability, belt construction, idler roll length, belt and idler contact length, Finite Element Analysis modelling and field installations in coal, bauxite and iron ore applications. This information leads to new techniques that can be employed to study and validate optimum idler geometry and belt construction selection for a new or modified conveyor and its specific operating parameters before installation. The joint submissions from a belt manufacturer a conveyor structure original equipment manufacturer (OEM) and conveyor designer are brought together in this paper to reinforce the theme that the belt and conveyor structure need to be considered together, as a total conveying package solution. The sourcing option to specify a significantly new conveyor structure and belt construction independently without validation can in some cases lead to an inferior outcome.

1.1 Location of Trough Idlers

Trough idlers are one of the basic components of most belt conveyors and their relative location on the conveyor is illustrated in Figure 1.(Ref #6)
1.2 Background to 5 Roll Idler Design

- For approximately 15 years in Australian coal mining there has been a preference for 5 roll trough idlers over 3 roll design. The main reason is the roll lengths are shorter than they would otherwise be with equivalent 3 roll geometry and therefore lighter in weight and easier to handle particularly for 1800mm and greater belt widths.
- Iron ore and bauxite mining has introduced 5 roll trough idlers more for capacity increase and improved loading by employing higher trough angles such as 55 degrees.
- The 5 roll designs can be either “Inline” or “Offset” as shown in Figure 2 and 3. The “Offset” design usually, but not always, has the centre and outer wing idlers leading and the inner wing idlers trailing, compared to the direction of travel.

Figure 2  Inline Trough Idlers

Figure 3  Offset Trough Idlers
1.3 How 5 Roll Idler profile can originate.
There are numerous instances across the bulk handling industry adopting 5 roll trough sets on the carry side of a conveyor belt. However, upon closer review, there are far less instances of the adopted profile being optimised for the specific details of the application. Two typical problems are excessive idler gap and lack of contact as shown in Figure 4 and 5. In many instances the trough idler roll profile is driven by:
- Standard Design, Cross Section or Construction Efficiency
- In some cases simply by widening one or more of the rollers
- Without regard to belt characteristics, maximised belt or component life, nor maintainable component masses.

![Figure 4 Belt pinching due to Excessive idler gap](image1)

![Figure 5 Belt skating due to lack of contact](image2)

2. Design Elements impacting Belt Support and Capacity

2.1 Application factors to be considered for Optimal 5 Roll Idler Design
The optimal solution to the 5 roll layout will therefore be a function of detailed application factors including:
- Required burden cross section and belt speed
- Load density and surcharge angle
- Normal and peak loading throughput capacity
- Belt support & idler spacing
- Transverse belt flexural stiffness and troughability
- Belt tension and allowable belt sag%
- Idler diameter and junction gap
- Idler length and angle
- Fixed or garland conveyor structure
- Power consumption
- Required minimum theoretical roller bearing life
- The standard range of roller bearing bores and dynamic ratings
- The standard range of shafting bar stock size

2.2 Compatibility between belt and 5 Roll Idler Design.
The natural unrestrained transverse flexure profile of a conveyor belt is a continuous curve of varying radii. The belt will form a shape typically having greater curvature in the centre and less curvature at the edges. In contrast, a trough roller set must always present a series of flat rollers and point changes of angle, along with potential unconstrained zones at the “pinch gaps” if they exist, between roller ends.

The degree to which the belt conforms to the trough set profile will be a function of the natural belt flexure shape, the trough profile of the idler rolls and the effect of the burden load.
Ultimately under sufficient load, the belt will conform generally to the trough profile but at varying degrees of localised stresses in the belt cover and carcass. This issue grows in significance as higher strength and associated stiffer constructions are encountered which is the usual domain of high capacity conveyors and 5 roll trough sets.

Clearly an optimised profile design must minimise the localised stresses in the belt by providing a supporting shape that suits the natural belt flexure. It is self-evident that belt life can be improved if these stresses are minimised.

Furthermore, the closer the trough profile matches the natural belt flexure shape, (Figure 6) the better will be the belt support or roller contact length under low load conditions thus leading to more predictable belt tracking behaviour across all loading conditions. Trough profiles that do not sufficiently match the natural belt flexure profile can lead to situations under low or no load (empty belt) conditions where the belt has limited contact on the rollers and the tracking effect by the rollers is lost.

Where offset idlers also overlap or the ends leave no transverse gap, there can be negligible opportunity for belt pinching. However for in line idlers such as found on garland suspended design there are gaps which need to be considered. The main factors that determine whether or not belt pinching will occur are gap width, belt thickness, idler angle change at the junction, idler spacing, burden load, belt speed and belt tension both running and transient.

![Figure 6](image_url)  Example of good belt support in a 5 roll trough set

Idler spacing Figure 7, impacts idler bearing fatigue life, idler shaft diameter, idler junction gap, sag between idler sets, belt tension and belt stiffness.
2.3 Transverse Belt Flexibility & Troughability

Selection of a conveyor belt construction begins with rated carcass tensile strength, safety factor, cover gauges, cover and core compounds, conformance to required standards and sometimes government statutory requirements for example in underground coal applications. The selection process always leads to a review of the transverse belt flexibility. The most common method is to analyse the troughability at the operating temperature and one of the routine conveyor belt tests as specified in all major belt manufacture standards is the troughability ratio (or factor). The latest international troughability standard is ISO 703 2007. Within the Scope is mentioned “This International Standard specifies a method for determining the transverse flexibility (troughability) of a conveyor belt, expressed as a ratio F/L. A test piece consisting of a transverse section of belt (L) equal to the belt width is suspended at both ends with the carrying face uppermost so that the belt ends are in the same horizontal plane. The troughability is determined by measuring the maximum deflection (F) of the test piece under its own weight. It is expressed as the ratio of F/L. Typically the measurement is taken a minimum of 16 hours after manufacture and after conditioning for 8 hours at 23±2°C. A typical arrangement is shown in Figure 8.

Figure 8. Typical troughability arrangement per ISO 703

L= Belt Width
F/L= Troughability Ratio
Determining the troughability ratio F/L per ISO 703 is straightforward and relatively easy to undertake at the laboratory temperature specified above.

The troughability ratio F/L reduces with decreasing temperature. ContiTech used a walk-in refrigeration chamber to allow the troughability ratio to be measured at temperatures down to -35°C to validate applications at site operating conditions. Figure 9.

Figure 9. Low Temperature Troughability Chamber Rig

The troughability ratio F/L also decreases with decreasing belt width. An example of this relationship between belt width and troughability ratio F/L for a fabric belt construction PN1260/4 4x4 at three belt widths, is illustrated in Figure 10. Similarly the variation in F/L versus belt width for an ST7000 steel cord belt is illustrated in Figure 11.

Figure 10   PN1260/4 4x4 Belt in troughability test rig at three belt Widths.

Figure 11   ST7000 Belt in troughability test rig at three belt Widths.
The ISO 703 defines how to measure the troughability ratio F/L. The first question arising after obtaining the ratio F/L is:

What is an acceptable F/L for the given conveyor idler geometry and operating parameters?

Australian Standards for steel cord conveyor belt AS1333 1994 and fabric conveyor belt AS1332 2000 list minimum troughability values under Table 5 and Table 8 respectively with a note that the values apply to a belt formed into a trough with 3 equal length idlers.

There are no formal standard guidelines for minimum troughability with 5 roll trough idler geometry. The industry loosely and independently relies on empirical troughability ratio F/L recorded for each application to use as a predictor for a new application.

More importantly the troughability ratio F/L on its own is of limited value. What is important is the natural shape the belt takes as it is suspended in the troughability test rig and the difference between this and the intended idler trough profile.

2.4 Measurement of Transverse Belt Stiffness

The ability of the belt to conform to the shape of the trough idlers is dependent on the belt transverse stiffness. This transverse stiffness can be determined by using a 3 point beam test jig where the deflection between 2 beams is measured as a vertical load is applied to the sample between the beams. Refer to Figure 12

If the intended idler geometry closely matches the troughability shape, it is very likely that there will be a good contact length on the idlers. It has been long known that good contact length results in good tracking performance and conversely lack of contact results in poor tracking performance.

Figure 12. Typical 3 point beam test to measure force versus deflection (transverse stiffness)
2.5 Belt Construction, Transverse Flexibility & Stiffness

Steel cord reinforced conveyor belts transverse flexibility are mainly influenced by:
1. Belt individual cover gauges and overall gauge
2. Cord diameter and cord pitch
3. Presence of any transverse reinforcement
4. Belt width
5. Operating temperature and belt compound stiffness properties.

Fabric reinforced conveyor belts transverse flexibility are mainly influenced by:
1. Belt individual cover gauges and overall gauge
2. Ply and skim gauges (carcase)
3. Fabric weave and yarn selection
4. Belt width
5. Operating temperature and belt compound stiffness properties

The conveyor belt selection must take into account the optimum combination of the above mentioned components to provide the required service life and transverse flexibility and stiffness for the applications intended.

2.6 Component Design

The usual loaded profile of a troughed conveyor concentrates the mass load in the centre portion of the belt section. Both the trough profile (Concave) and burden shape (Convex) contribute to this result, creating a lens shaped cross section of material supported by belt and rollers.

In simple terms, most of the load is in the middle third of the cross section and hence the old rule of thumb that two thirds of the load is supported by the centre roll in a three roll set.

![Figure 13  5 Roll Trough Load Profile](image)

Similarly in a 5 roll set design, Fig 13, a significant percentage of the total load exists over the central part of the profile. The side or wing rolls have much less load imposed on them per unit length than the central rolls. Hence, from a perspective of component optimisation, there are valid reasons to consider the length of rollers in the profile, their imposed loading, resultant bearing lives and shaft deflection.

Shorter rolls in the centre of the profile will create better load distribution between the rollers and hence better balance in required bearing size for life and shaft size for control of deflection. Such adjustment will in turn lead to minimised overall component masses and improved maintainability and ergonomic outcomes.

Thus, the optimal design solution for a 5 roll trough set tends towards shorter rolls in the centre for reasons of component engineering.
The optimal trough profile for belt support discussed earlier has higher rates of curvature in the centre of the profile and lesser rates at the edges. Conveniently, a higher rate of curvature can be best matched by shorter straight segments, that is, shorter roll face lengths in this same area. Thus the desired outcomes of improved belt support and component design efficiency are simultaneously served by a layout that adopts shorter rolls in the centre of the profile and relatively longer rolls at the wings.

![Figure 14. Optimised 5 Roll load profile](image)

### 3. Classification of 5 Roll Trough Idler Configurations

In addition to the traditional equal length 5 roll trough idler design there are two additional typical 5 roll trough idler designs. Both these involve unequal length idlers. One type has longer outer wing idler as shown in the component design above and the other type has a longer centre idler. In some cases these new types have been born out of the need to expand existing idler geometry to suit wider conveyors. With recent experience with all three types it is possible to classify them and show examples of how they may appear. Note where existing conveyor structure has been widened there can be significant increases in idler junction gaps from use of existing idler rolls which can lead to belt pinching and premature belt failure.

Within the range of 5 Roll geometry there are 3 distinct configurations and we classify them as follows regardless of trough angle.

- **Type 1**: 5 Equal length idlers
- **Type 2**: 3x Short centre and Inner wing idlers, 2 x long Outer wing idlers
- **Type 3**: 1x Long centre idler, 4x short inner and outer wing idlers

Examples of the three types of geometry are shown below.

![Figure 15 Type 1 Geometry](image)
4. Comparative Belt Capacity

Illustrated below are comparative edge distance for examples of the 3 types of idler geometry. There are an infinite number of uneven roll length combinations. Existing system examples have been chosen for illustration purposes. The examples are based on 5,500 tph load capacity, material density 800kg/m3, 25 degree surcharge angle and belt speed 5.2m/s on 1800mm wide structure with an equal overall idler length of 2045mm. A summary of the relative edge clearance is shown in Table 1.

In this example the Type 2 idler geometry could increase the capacity to 6000 tph with the same edge clearance as the Type 3 idler geometry with 5,500 tph capacity.
Type 2 Geometry

![Type 2 Geometry](image)

Figure 19 – Type 2 Geometry 5,500 tph

Type 3 Geometry

![Type 3 Geometry](image)

Figure 20 – Type 3 Geometry 5,500 tph

<table>
<thead>
<tr>
<th>Geometry Type</th>
<th>Cema Min Edge (mm)</th>
<th>Calculated Edge (mm)</th>
<th>Cema % Loading</th>
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<td>162</td>
<td>87.8%</td>
</tr>
<tr>
<td>2</td>
<td>122</td>
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<tr>
<td>3</td>
<td>122</td>
<td>148</td>
<td>91.4%</td>
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Table 1  Calculated CEMA edge distance for 3 types of 5 roll idler geometry.

5. Application Experience

5.1 Maingate Conveyors

Such optimised profiles as described in 2.6 above have been adopted in practice for both permanent installations and portable underground “maingate” conveyors with notable success. Tracking performance on light load conditions with a high strength fabric belt has been very good, displaying lateral stability under all load conditions.
Further, component and assembly masses for 1800 mm wide maingate structure have been significantly reduced at one major mine site targeting improved ergonomic and safety outcomes. The improved mass also provided a dividend in cost efficiency (less steel equals less cost) and improved assembly and recovery times.

Figure 21 Optimised 5 roll Trough Geometry in Maingate structure

5.2 Belt to Trough Idler Contact Length

A set of circumstances arose recently, which resulted in the same belt width and construction being installed on two different types of 1800mm wide 5 Roll trough idler geometry. There was a significant difference in empty belt tracking performance between the two geometries. The belt tracked very well on the Type 2 geometry trough idlers and poorly on a Type 3 geometry trough idlers.

In Section 2.2 above, it was stated, “The degree to which the belt conforms to the trough set profile will be a function of the natural belt flexure shape, the trough profile formed by the idler rolls and the effect of the burden load.”

As a way of comparing the degree to which the belt conformed to each trough idler profile the belt to trough idler contact lengths were measured for each conveyor. The Type 2 geometry trough idlers displayed nearly double the Type 3 geometry total trough idler to belt contact length.
<table>
<thead>
<tr>
<th>Geometry</th>
<th>Centre</th>
<th>Inner Wing</th>
<th>Outer Wing</th>
<th>Total Contact Length</th>
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<tbody>
<tr>
<td>Type 2</td>
<td>140mm</td>
<td>80mm</td>
<td>250mm</td>
<td>44%</td>
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</tr>
<tr>
<td>Type 3</td>
<td>50mm</td>
<td>25mm</td>
<td>155mm</td>
<td>23%</td>
<td>25</td>
</tr>
</tbody>
</table>

5.3 Deep Trough Parabolic Profile 5 Roll Carry Idler Sets

Five (5) roll sets have been used on a number of recent above ground projects. These include:

- A primary crusher belt width increased from 1500mm to 1800mm. The 5 roll sets allowed the wider belt to fit into the existing tunnel with a large edge clearance to contain the large lumps. So the planned “hungry” boards (fixed skirting above the outside belt edge) were not required. The work changed the design of the loading point to allow a soft impact design to be implemented. (Ref. 7)

- All loading points at a new iron ore project. Figure 24

- A 22km Overland Conveyor system. 1500mm 5 roll x 55 degrees Figure 27
• Primary system iron ore—All loading points.
• Bauxite Project. All primary conveyors and all other loading points.

5.4 Case Study

Deep trough parabolic profile 5 roll idler sets were successfully used to achieve a capacity increase for an existing conveyor from 3200tph to 5000tph. The belt width was changed from 1000mm 1050mm, speed unchanged at 6.6m/s.

A key issue in using steep wing 5 roll sets is the troughability of the belt. On this project, the challenge was to get the 1050mm wide x ST2024 belt to trough on the steep winged 5 roll set. Using ContiTech design criteria a special long outer wing rolls idler (Type 2 geometry) was developed for the application.

A 1050mm ST1100 belt was tested for troughability in the laboratory, Figure 26, then tested in a plywood model to confirm that the long outer wing rolls gave good belt to roll contact. The belt contact was considered an adequate percent of belt width, Figure 27. Subsequent testing on a troughability rig, Figure 28, showed that a 1050mm ST2024 belt also had good belt to roll contact.

Ultimately, the natural parabolic shape of the belt dictated the roll geometry. Based on the testing, a maximum outer wing angle was selected. With this configuration the volumetric capacity exceeds requirements 5000tph, Figures 29 and 30.
Figure 27 1050mm ST1000 12X5 on ContiTech Plywood Model with good belt contact

Figure 28 1050mm ST2024 on Design Engineer’s Test rig

<table>
<thead>
<tr>
<th>Geometry Type</th>
<th>Cema Min Edge (mm)</th>
<th>Calculated Edge (mm)</th>
<th>Cema % Loading</th>
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<td>2</td>
<td>80.6</td>
<td>131.6</td>
<td>77.2%</td>
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</table>

Figure 29 The volumetric capacity exceeded the requirements 5,000 tph

The previous section, above, outlines an example of a test belt being first placed in a troughability fixture per ISO 703 and then a longer section was placed in a plywood model to determine the contact length between the belt and the prospective idler geometry. Using a mathematical computer approach more variations can be simulated to optimise the belt and trough idler geometry profile. This can be done using a special Finite Element Analysis (FEA) model for conveyor belts. Figure 31 shows the basic model. ContiTech has developed a special FEA model for conveyor belts with the unique and specific non-linear properties for each rubber compound.

Steps involved in the FEA analysis:

1. Material properties used in the FEA model for the belt covers and carcass are generated with laboratory tests.

2. For each specific belt construction a FEA model utilizing the belt covers and carcass material properties is used to predict troughability ratios F/L and the suspended belt profile. Validation tests of the FEA prediction versus actual belt shape show excellent correlation, Figure 32.

3. Based on the FEA shape prediction, contact length on each idler as well as horizontal and vertical forces on each of the idlers can be generated for different 5 roll trough idler geometries. The FEA model evaluates different belt widths and simulates belt tensions from zero to operating tension. Figures 33 & 34

ContiTech’s FEA technology provides a useful tool to predict the contact length between belt and idler for different belt constructions and idler geometries at different belt tensions with a goal of improving belt tracking.
FEA Model Description

Figure 31 FEA Model Elements, Belt and idler geometric positions.

Figure 32 FEA Predicted Troughability and actual profile showed good correlation.

New Testing Fixture
7. Conclusions

1. 5-Roll idlers are increasing in popularity due to (a) lower roll weights which facilitate maintenance, and (b) higher capacities than three roll idlers. But, they pose new challenges as they can create poor belt tracking conditions if their geometry is not matched to the belt.

2. 5-Roll idlers can be categorized into three types.
   a. Type #1, 5 equal length rolls,
   b. Type #2, 3 short center, 2 wing rolls,
   c. Type #3, 1 long center, 4 short inner and outer rolls

3. Different capacities, belt support and tracking performance outcomes can be explained and predicted for these three types of 5 Roll trough idler geometries. Details are outlined and presented in this paper.

4. Special non-linear Finite Element Analysis models have been developed to predict belt matching performance with respect to idler geometries. The model predicts idler contact lengths which impact tracking performance. The model has been validated with practical lab tests.
5. Actual conveyor examples were studied that demonstrate real benefits that were achieved by optimising the idler geometry.

References
1* Minerals Council of Australia Year 2012-2013
2** Minerals Council of Australia Year 2012-2013
3. Statistico.com
5. Soft impact loading points. (See IIR conference paper June 2007. Handling Primary Crushed Ore by Gary James)
6. CEMA