AN EXPERIMENTAL INVESTIGATION INTO THE INFLUENCE OF SKEWED IDLER ROLLS

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ABSTRACT

Skewed idler rolls are often used in belt conveyors to deliberately track belts. Applications include dynamic belt tracking systems, tilted wing rolls or deliberately misaligned idler frames. Additionally, skewed idler rolls may be introduced unintentionally as a result of poor manufacturing tolerances, structural misalignment, ground settlement, etc. Whether intentional, or otherwise, the influence of the skewed idler roll on the belt tracking performance is an area of interest for plant operators and designers, and while there have been a number of analytical investigations into the thrust force that a skewed idler roll imparts to a conveyor belt, there have been limited experimental investigations to prove the accuracy of these predictions.

To examine the forces acting on a skewed idler roll this paper investigates the forces acting for static and dynamic loading scenarios. To achieve this, two test rigs located at the University of Newcastle have been developed. These testing rigs allow for measurements of the coefficient of friction and resulting dynamic forces to be quantitatively determined for a range of skew angles. A comparison of analytical investigations and experimentally measured results are shown where the prediction of the forces acting on a skewed idler roll in relation to belt mistracking can be undertaken.

1. INTRODUCTION

Conveyor belt mistracking is one of the critical operating problems that occurs with any belt conveyor system. Causes and counter-actions are readily known, however, they are typically based on empirical data. The issue of conveyor belt mistracking was initially observed during the industrial revolution, where flat belts were first used on drive trains [1]. There are numerous causes for the mistracking of a conveyor belt [2,3] where each cause will typically influence the other. It is impractical to detail all possible reasons which cause belt mistracking however it will be appropriate to briefly mention some of the key causes. From all the possible causes, skewed idlers are one of the key factors for the mistracking of conveyor belts and will be discussed in detail in the following section.

1.1 MISALIGNMENT OF IDLER ROLLS

The alignment of idler rolls has a significant influence on the tracking or mistracking of a conveyor belt. Small differences from the ideal aligned position can result in the substantial mistracking of a conveyor belt. These considerations are based on idler stations which contain fixed idler rolls, which cannot move when exposed to an impact, unlike 'garland' type suspended idler sets. The misalignment of idler stations can be separated into translational and rotational orientations. The co-ordinate notation used is based on those documented in CEMA [2] where a schematic is shown in Figure 1.

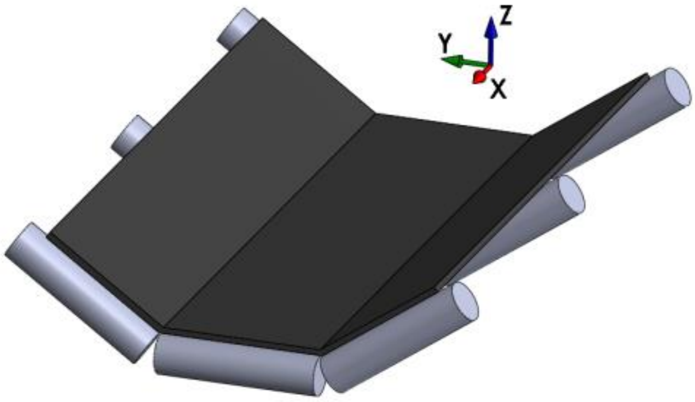


Figure 1. Schematic of troughed conveyor belt on idler rolls using CEMA co-ordinate notation

TRANSLATIONAL MISALIGNMENT

Three possible translational misalignment orientations can occur in the x-direction, y-direction and z-direction. A misalignment in y-direction will shift the idler station relative to the belt centre line. Mistracking will occur as an effect of the self-alignment of the conveyor belt. The belt will follow the lowest points of the idler stations due to its self-centring behaviour caused by the belt and bulk material mass.

ROTATIONAL MISALIGNMENT

A rotation around the x-axis is typically used to assist the conveyor belt in negotiating horizontal curves. Due to the entire mass of the belt and the bulk material attempting to reach the lowest possible value of potential energy, the belt will move sideways.

The rotation of an idler station around the y-axis is also known as a tilted idler station. Depending on the conveying direction, the tilt of the idler station can give a positive influence on the self-centring of the belt. If idler stations are tilted forwards in the conveying direction, the belt is deformed which results in a self-alignment. If all stations are tilted, the belt will run with much more stability but with an increase in energy consumption due to belt slip relative to the wing rolls.

A rotational misalignment around the z-axis is known as a skewed idler station. The skewed idler station will steer the belt in the normal direction of the idler. The lateral movement is directly proportional to the angle of skew, as long as the force acting on the belt is smaller than the maximum frictional force between the belt and idler. In the case where the force is larger than the maximum frictional force, the belt will slip above the idler.

1.2 ECCENTRIC BULK MATERIAL LOAD

There are two typical causes which lead to an eccentric (off-centred) load of a bulk material being transferred to the conveyor belt. The first case occurs when the bulk material is being loaded eccentrically onto a centred belt. This will generally be attributed to a poorly designed transfer chute or from a transfer chute blockage caused by a problematic bulk material. The weight force of the eccentrically loaded bulk material results in a belt deflection which causes lateral movement. A positive feedback loop is established if the belt is not centred before the transfer chute. The bulk material is therefore loaded onto an already off-centred running belt. The second case occurs when a bulk material is centrally loaded onto a misaligned running belt. This will not result in increased belt mistracking because the weight force keeps the belt stable in its off-centred position.

1.3 ADDITIONAL CAUSES

Some of the additional causes for belt mistracking include; misaligned pulleys or the form of idler rolls and pulleys. The shape of idlers or pulleys can change during the operational running of the system where cohesive bulk materials stick on the pulley surfaces. The shape has a direct influence on the movement in the y-direction. Crowned pulleys have a self-centring effect and tapered pulleys result in a constant sideways movement. The fabrication of the belt also has an influence on the running behaviour. Some belts are produced with a camber, so they will always run to one side. Additionally, the splice of the conveyor belt can lead to belt mistracking. If the splice is joined at an angle, this will change the lateral movement of the belt in relation to successive idler stations. Furthermore, uneven tension distribution in the conveyor belt is another major cause of mistracking.

2. FORCES ACTING ON A SKEWED IDLER ROLL

The resulting movement of a conveyor belt travelling over a skewed idler roll is shown schematically in Figure 2. If the belt moves in the direction of travel shown, and point “a” is the initial contact point between the edge of the belt and the idler roll, then point “a” will travel to point “a' ” during one quarter of a rotation of the roll. This will effectively displace the belt transversely a distance Δy as shown. It is important to note this translational movement will be governed by the physical boundary conditions of the conveyor.

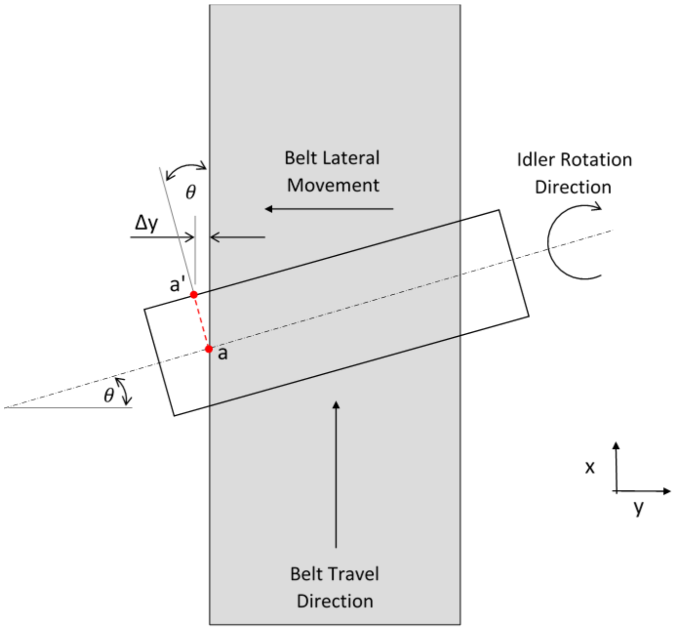


Figure 2. Schematic of conveyor belt travelling over a skewed idler roll

CEMA [2] provides a method to calculate the increase in longitudinal tension as a result of idler roll misalignment. The increase in tension, ΔT_{im}, is given by:

$$\Delta T_{im} = C_{im} \times (W_b + W_m) \times R_{rim} \quad (1)$$

Where: W_b = Belt weight

W_m = Bulk material weight

R_{rim} = Idler roll misalignment factor = 1.0 (CEMA [2])

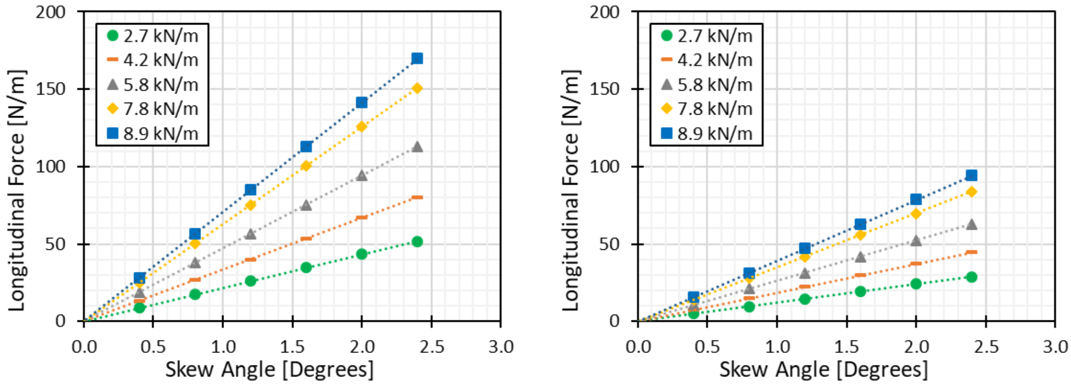
$C_{im} = C_{bi} \times a_{im}$

C_{bi} = Coefficient of friction between belt cover and idler roll

a_{im} = Misalignment of idler axis to belt longitudinal axis

$a_{im} = \theta$ (From Figure 2)

Figure 3a shows the calculated longitudinal tension increase resulting from a skewed mild steel idler roll for a range of loads and skew angles. A friction factor of 0.45 was assumed from experimental measurements (shown in Figure 8) for the coefficient of friction between belt cover and idler roll. Figure 3b shows the calculated longitudinal tension increase resulting from a skewed HDPE idler roll for a range of loads and skew angles. A friction factor of 0.25 was assumed from experimental measurements (shown in Figure 8) for the coefficient of friction between belt cover and idler roll. It is appropriate to identify the idler roll misalignment factor, R_{rim}, is typically assumed as 0.67 for regenerative conveyor flights. In the case of the system tested, the idler roll misalignment factor was assumed to be 1.0 (CEMA [2]).



a) Mild steel idler roll

b) HDPE idler roll

Figure 3. Calculated longitudinal tension increase due to a skewed idler roll

Furthermore, it is worth noting that CEMA [2] does not provide a relationship to calculate the axial force experienced by the idler roll due to misalignment. This would be particularly important in order to predict the design loads for idler bearings in addition to the structure of belt tracking systems.

3. EXPERIMENTAL MEASUREMENTS

To gain an understanding of the complete force relationship acting on skewed idler rolls, experimental measurements were to be undertaken. Two sets of experiments were developed to consider both static and dynamic conditions. The following section outlines the developed test rigs and a summary of the key experimental measurements.

3.1 SURFACE PROPERTIES

To determine the friction properties of the tested idler rolls it was deemed necessary to determine the surface properties of the belt samples and idler rolls. For the measurement of the surface roughness of the belt samples and idler rolls that have been used, there are two common height measurements used, namely, R_a, a Centre Line Average (CLA) roughness and R_q, the Root Mean Square (RMS) roughness. A schematic of the method used for the determination of height measurements is found in Figure 4.

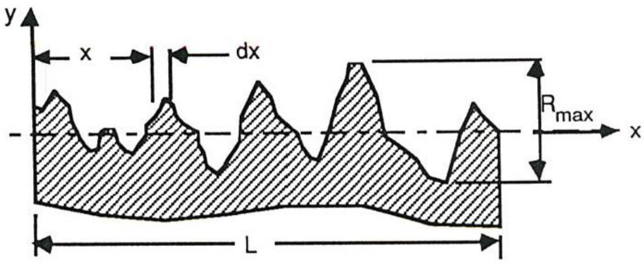


Figure 4. Schematic of roughness surface profile (Roberts, 1998)

The CLA roughness is the most common measurement method used and is determined by:

$$R_a = \frac{1}{L}\int_0^L |y(x)|\,dx \tag{2}$$

where: $|y(x)|$ is the absolute value of the coordinate height from the mean centreline.

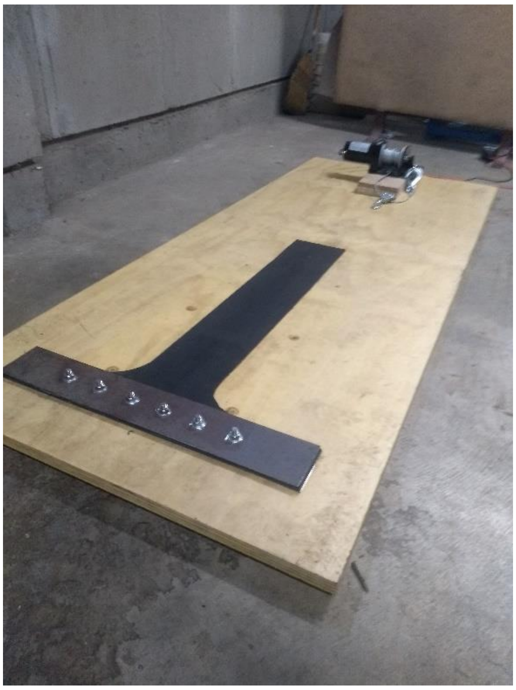
The calculated surface roughness of each belt sample was 2.5 µm for the static test rig (outlined in Section 3.2) and 2.7 µm for the dynamic test rig (outlined in Section 3.3). The roughness values for each tested idler roll is summarised in Table 1. The surface roughness has been determined in accordance with ASTM D7127 [4] using a stylus probe.

Sample	*Idler Diameter [mm]*	*CLA Roughness [µm]*
Mild Steel	127	0.23
Mild Steel	152	0.40
Mild Steel	178	0.77
PVC	152	0.78
HDPE	152	1.53

Table 1. Surface roughness measurements undertaken in accordance with ASTM D7127

3.2 STATIC PULL MEASUREMENTS

To test the coefficients of friction of idler rolls in contact with a conveyor belt, a bench scale testing facility was developed as shown in Figure 5. The test rig was designed to accommodate 200 mm long idler samples which could accommodate idler shell diameters of: 219 mm, 198 mm, 178 mm, 152 mm and 127 mm. Additionally, angles of 0°, 1° and 5° could be accommodated to investigate the influence of skewed idlers rolls and the measured coefficient of friction. The normal force acting between the idler sample and belt sample varied from approximately 42 kg (self-weight of the testing frame and idler roll) to approximately 112 kg in 10 kg increments during multiple tests.



a) Belt sample for friction pull tests

b) Loaded idler roll prior to experimental measurement

Figure 5. Bench scale friction pull test facility

During the experimental measurements, the breakaway torque requires a significant amount of traction, where static resistances within the system must be overcome. When a tractive force is applied to an interaction between an elastic body and rigid surface, regions of stick and slip develop [5]. The generated traction from each zone is superimposed to determine the total traction produced within the contact area. Incipient contacts contain a stick zone located within the centre of the contact, whereas this moves to the leading edge as the interaction begins to slide [6]. A typical friction pull measurement plot is shown in Figure 6 which illustrates the frictional force for a 152 mm diameter idler roll for a HDPE material. The presence of stick slip can be immediately identified for all tested materials where a constant pulling force was unable to be obtained as shown in Figure 6.

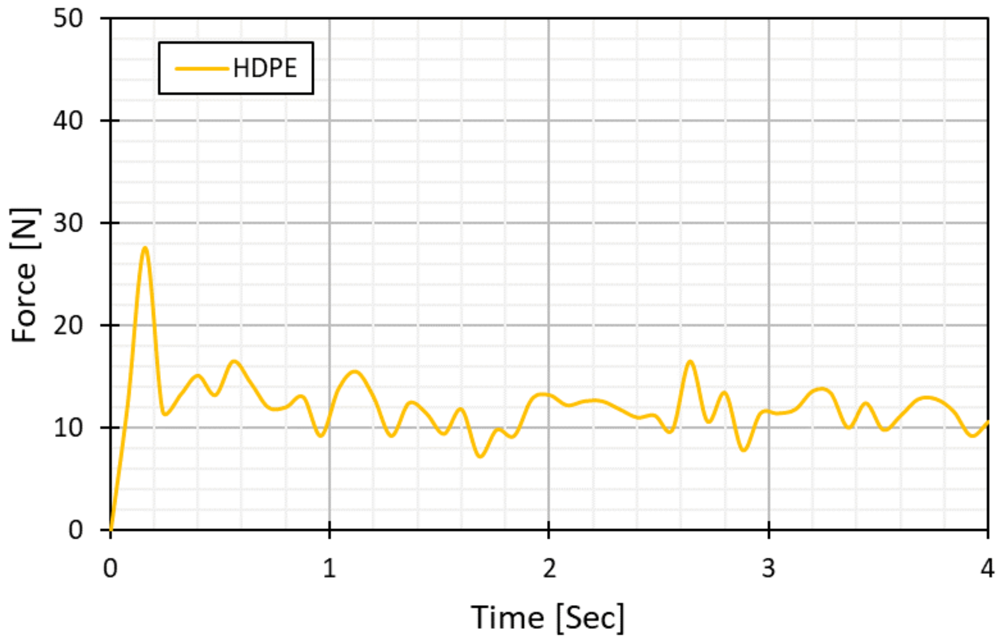
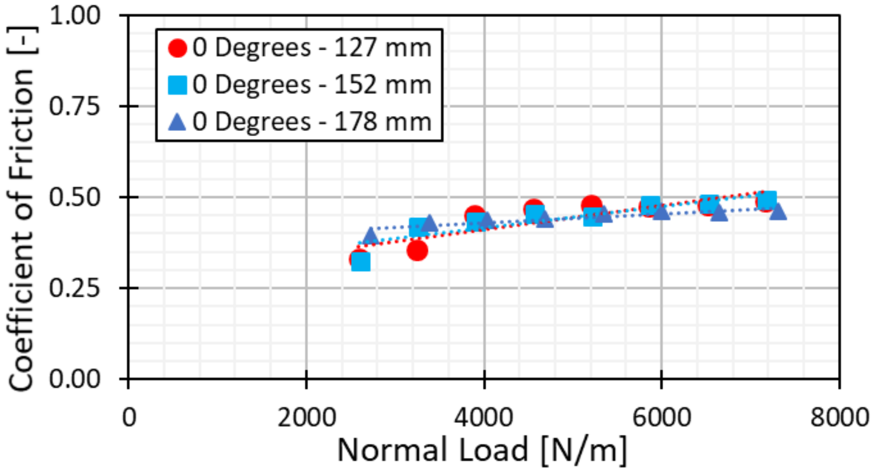
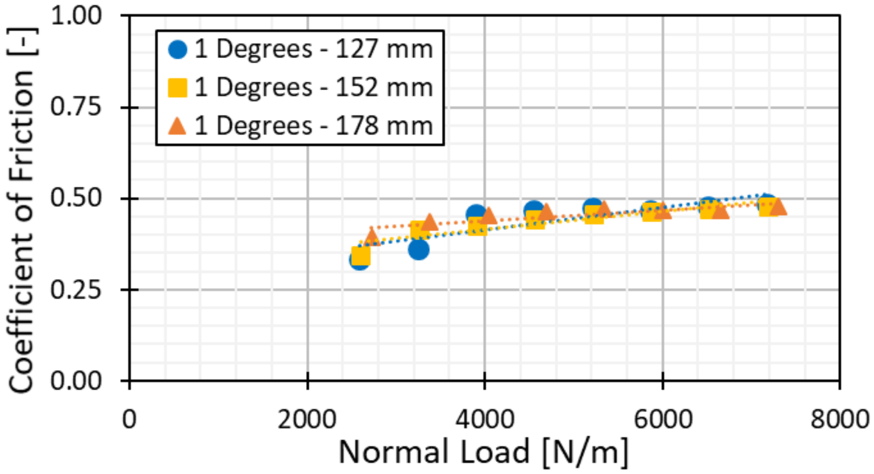


Figure 6. Typical friction pull measurement showing the influence of surface properties for HDPE material

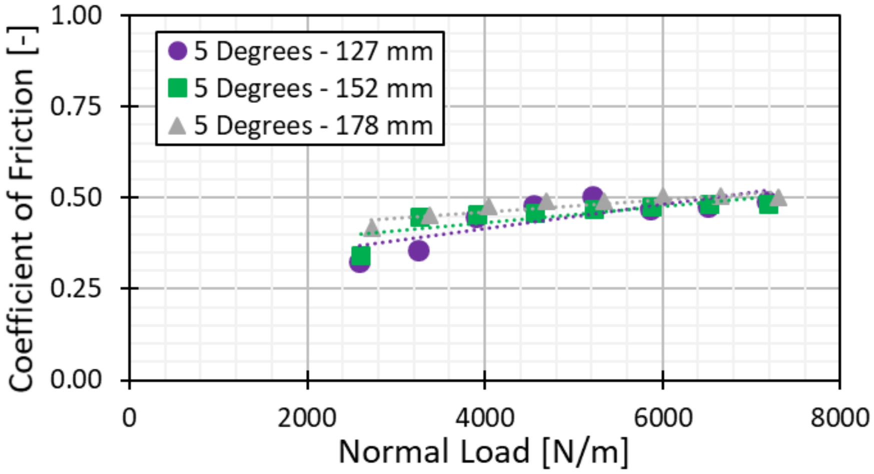
A summary of the coefficient of friction values obtained from the friction pull measurements are shown in Figures 7 and 8. The data has been analysed to consider the differences between idler roll diameter and idler roll material for angles of 0°, 1° and 5°. The differences between skew angles were also considered but not plotted due to the lack of variability of the coefficient of friction values obtained. When the diameter of the idler rolls is considered (as shown in Figure 7) a reasonably consistent coefficient of friction value results leading to the conclusion that diameter has little to no influence on the measurements. Conversely, if the material of the idler rolls for a constant diameter is considered (as shown in Figure 8), a much greater range for the coefficient of friction values can be observed.



a) Mild steel idler roll: 0 degrees

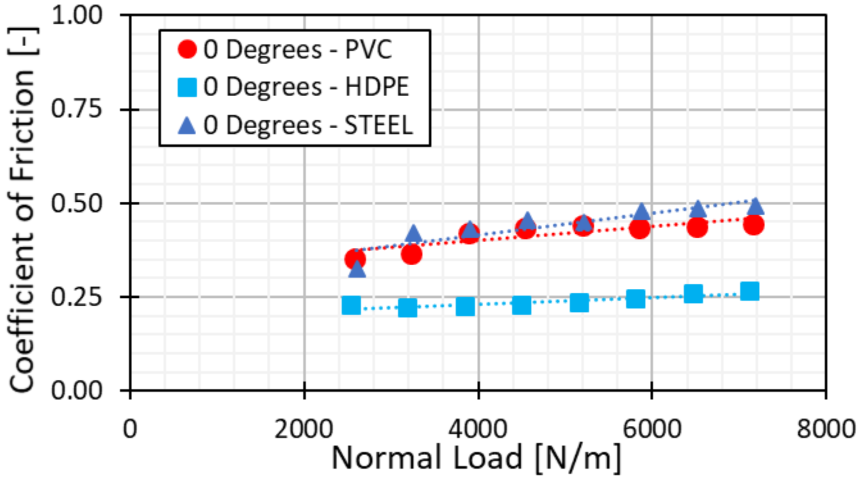


b) Mild steel idler roll: 1 degree

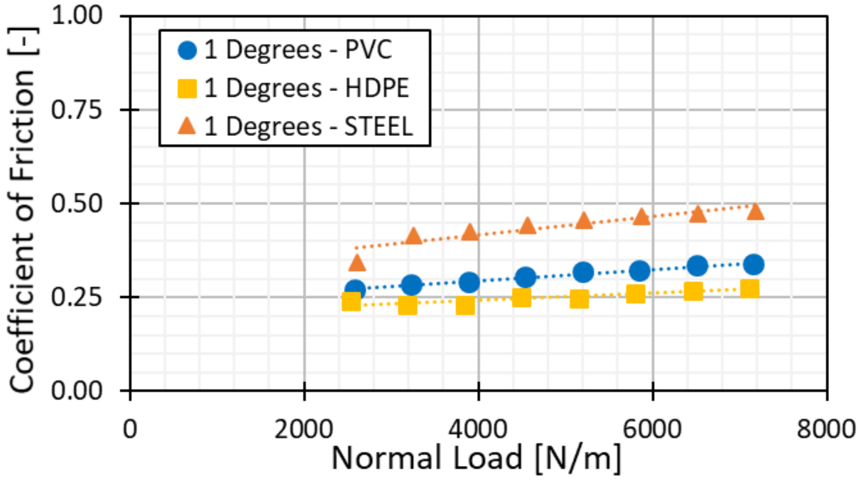


c) Mild steel idler roll: 5 degrees

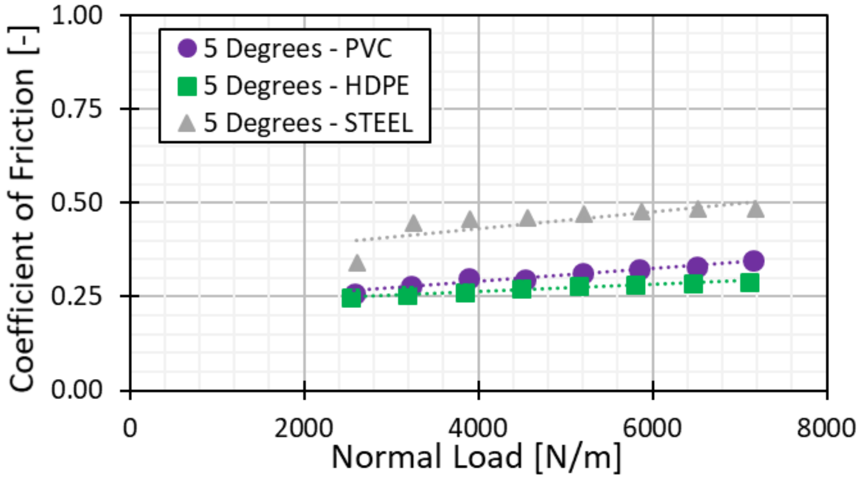
Figure 7. Idler roll diameter influence on coefficient of friction



a) 152 mm diameter idler roll: 0 degrees



b) 152 mm diameter idler roll: 1 degree

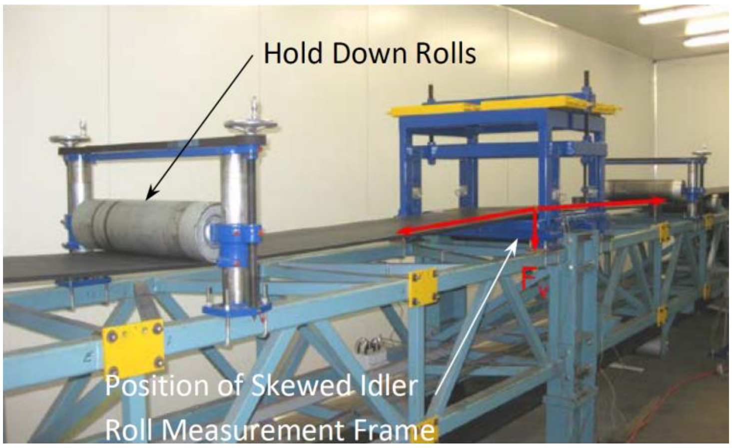


c) 152 mm diameter idler roll: 5 degrees

Figure 8. Idler roll material influence on coefficient of friction

3.3 DYNAMIC MEASUREMENTS

To test the axial force acting on a skewed idler roll in contact with a conveyor belt, a measurement frame was developed and incorporated into the large indentation rolling resistance test facility located at the University of Newcastle (as shown in Figure 9). The measurement frame was designed to accommodate a maximum idler shell length of 450 mm which could accommodate idler shell diameters of: 178 mm, 152 mm and 127 mm. Additionally, angles from 0° through to 5° could be accommodated to investigate the influence of skewed idler rolls and the measured axial force. The measurement frame was also mounted to linear bearings to measure the longitudinal force in the same direction as the travel of the belt (as shown in Figure 10). It will be appropriate to identify that the large indentation rolling resistance test facility uses a 400 mm wide flat section of belt where the influence of troughing angles cannot be analysed. The normal force acting on the idler sample for the experimental measurements were determined using the belt tension and a fixed sag ratio of 1%. The tested normal load varied from approximately 2.7 kN/m to approximately 8.9 kN/m where the force represents a load per unit width of belt.



a) Skewed idler roll location

b) Skewed idler roll measurement frame

Figure 9. Modified large indentation rolling resistance test facility incorporating skewed idler roll measurement frame

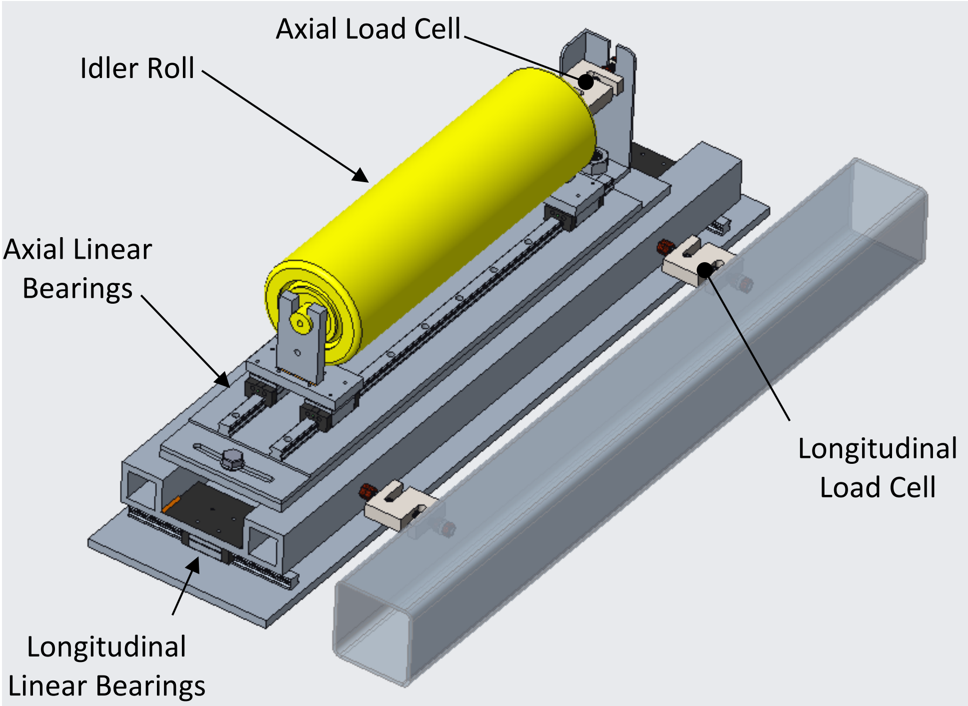


Figure 10. Skewed idler roll measurement frame

To gain an understanding into the influence of skew direction, measurements were undertaken in both right and left orientations in reference to the centreline of the belt. This was undertaken for both axial and longitudinal force measurements. An example of the axial and longitudinal force measurements for both right and left orientations are shown in Figure 11. The small variation in measurement values for both directions implies the tracking signature of the belt will be sufficient to test in either direction. For the case of the experimental measurements which are undertaken for this research, an average of both values will be used.

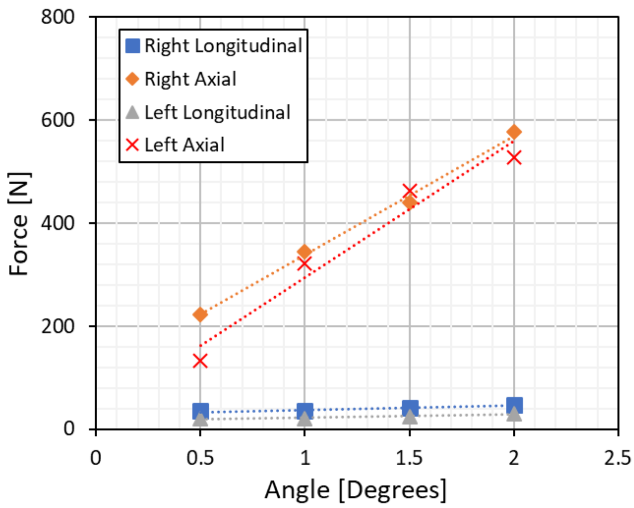
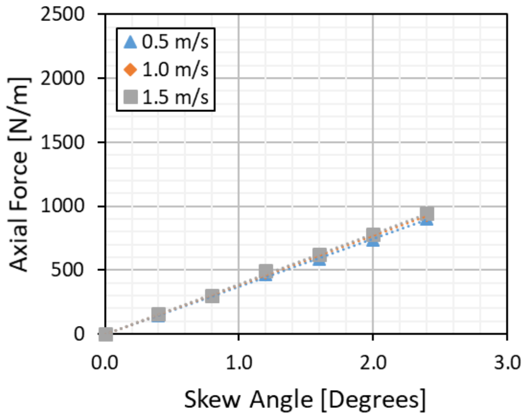
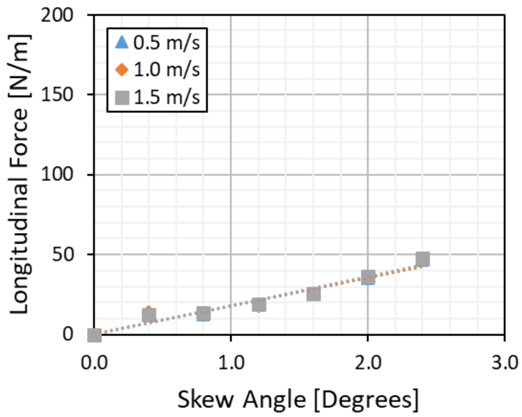


Figure 11. Typical dynamic measurement output showing the influence of skew

An example of the forces acting on the skewed idler roll due to the influence of belt velocity for a ø178 mm mild steel idler roll are shown in Figure 12. The data has been analysed to consider the differences between idler roll diameter and idler roll material for angles of 0.4° up to 2.4° which are undertaken in 0.4° increments. The differences between belt velocities were considered, however the full set of results have not been plotted due to the lack of variability of the obtained axial and longitudinal force measurements. It can be deduced that the velocity of the belt will have little to no influence on the axial and longitudinal force, as shown in Figure 12. The main influence for the belt velocity will be the rate at which the lateral movement of the belt will occur.



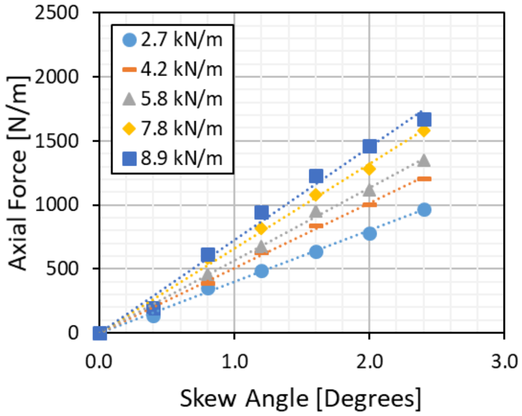
a) Axial force: 2.7 kN/m normal load



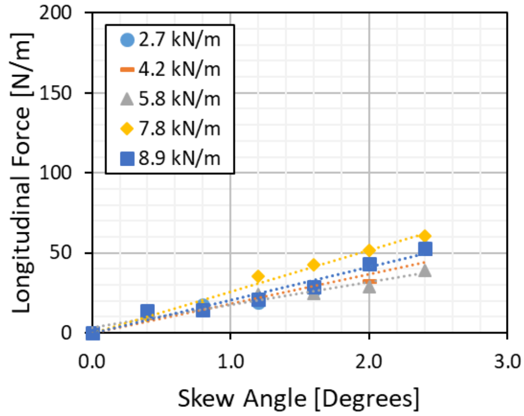
b) Longitudinal force: 2.7 kN/m normal load

Figure 12. Dynamic measurement results for ø178 mm mild steel idler roll showing axial and longitudinal forces relative to belt velocity

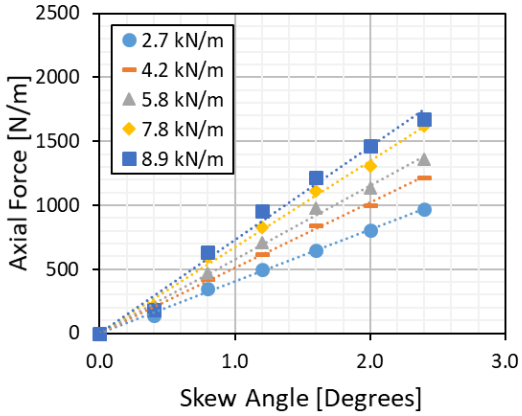
A summary of the forces acting on the skewed idler roll due to the influence of belt tension for a mild steel idler are shown in Figure 13 for a ø127 mm roll, Figure 14 for a ø152 mm roll and Figure 15 for a ø178 mm roll. Additionally, to investigate the influence of idler roll surface properties, PVC and HDPE idler rolls are investigated. The results of the PVC for a ø152 mm roll are shown in Figure 16 and the results of the HDPE for a ø152 mm roll are shown in Figure 17.



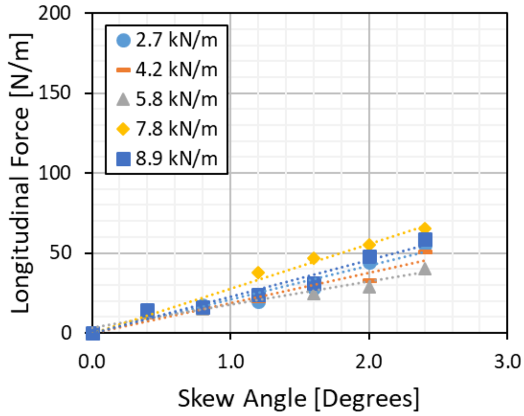
a) Axial force: 0.5 m/s belt velocity



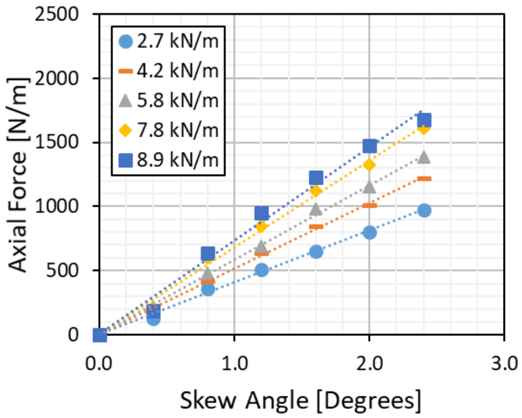
b) Longitudinal force: 0.5 m/s belt velocity



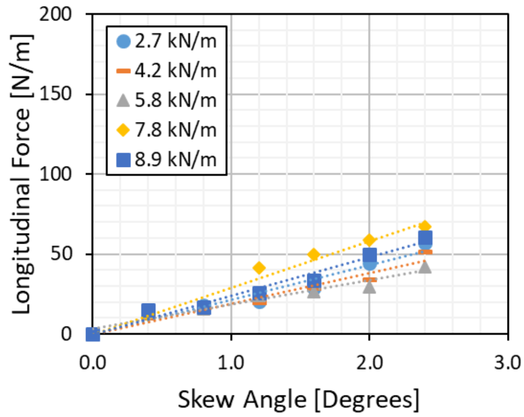
c) Axial force: 1.0 m/s belt velocity



d) Longitudinal force: 1.0 m/s belt velocity

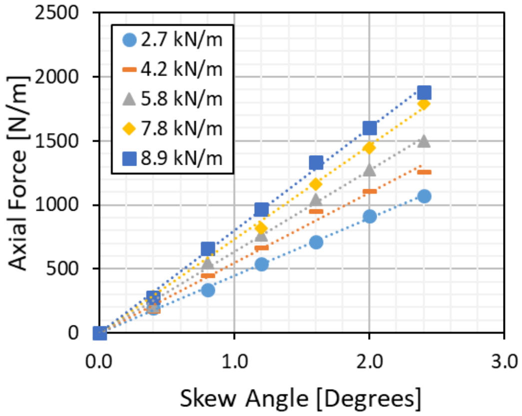


e) Axial force: 1.5 m/s belt velocity

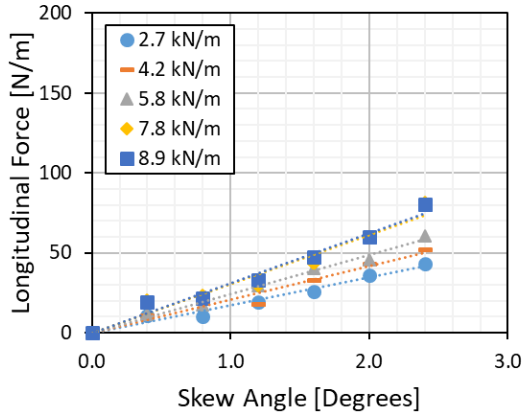


f) Longitudinal force: 1.5 m/s belt velocity

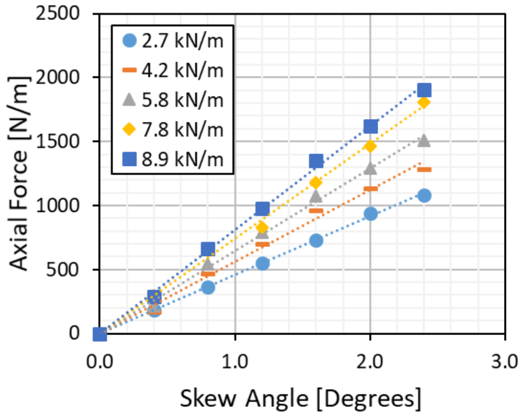
Figure 13. Dynamic measurement results for a ø127 mm mild steel idler roll showing axial and longitudinal forces relative to belt tension



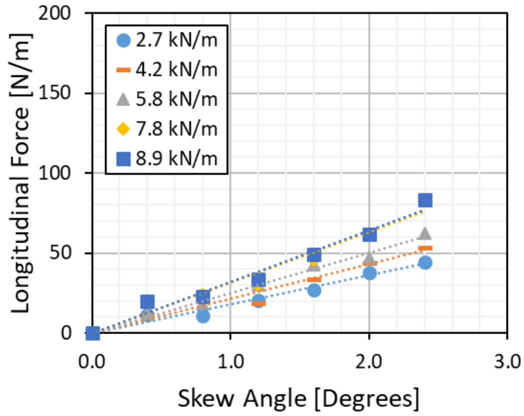
a) Axial force: 0.5 m/s belt velocity



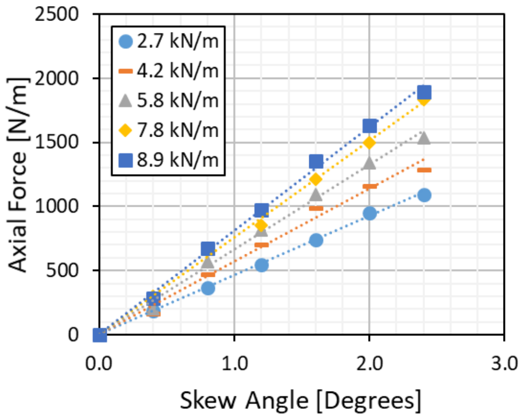
b) Longitudinal force: 0.5 m/s belt velocity



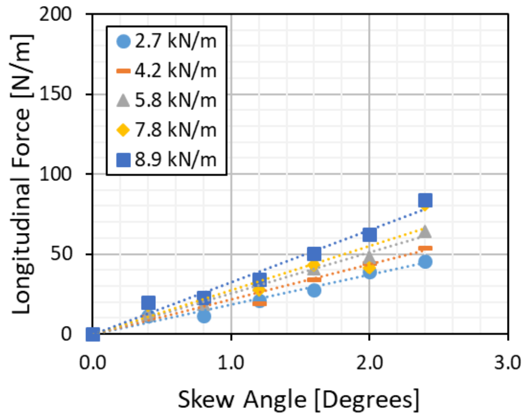
c) Axial force: 1.0 m/s belt velocity



d) Longitudinal force: 1.0 m/s belt velocity

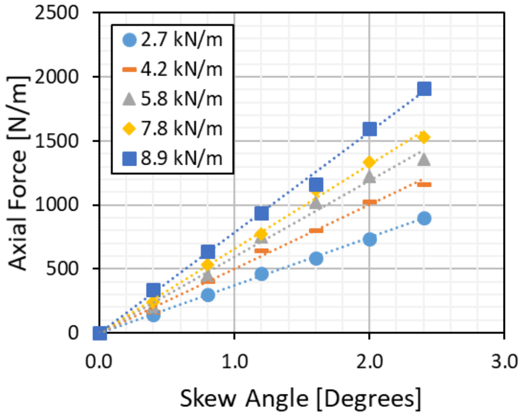


e) Axial force: 1.5 m/s belt velocity

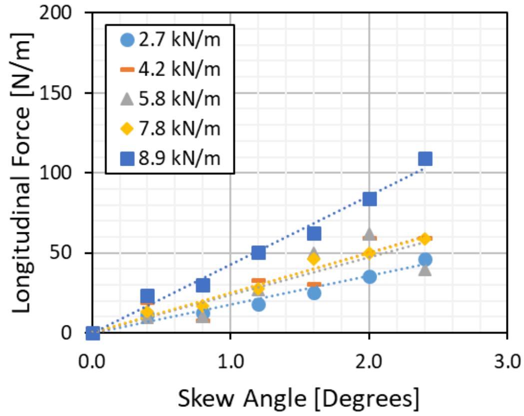


f) Longitudinal force: 1.5 m/s belt velocity

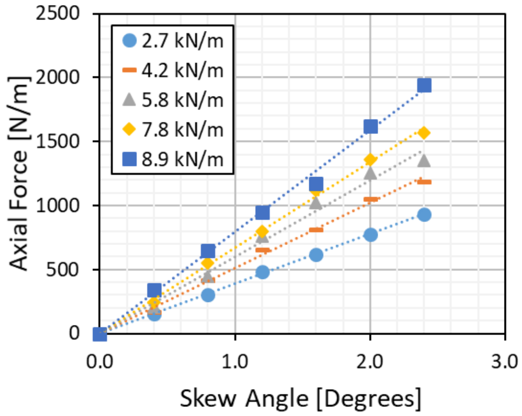
Figure 14. Dynamic measurement results for a ø152 mm mild steel idler roll showing axial and longitudinal forces relative to belt tension



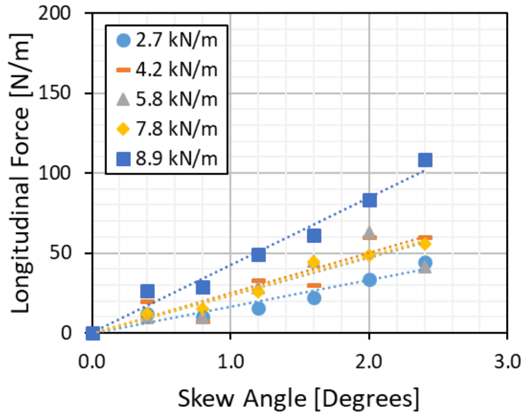
a) Axial force: 0.5 m/s belt velocity



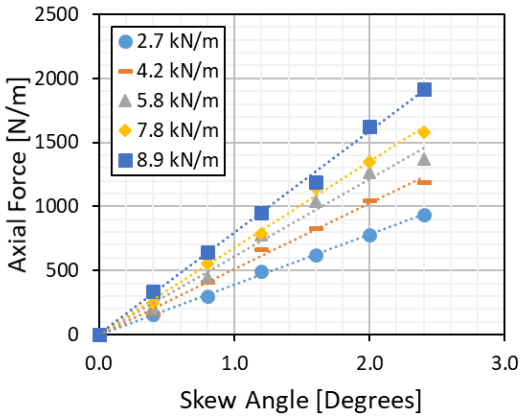
b) Longitudinal force: 0.5 m/s belt velocity



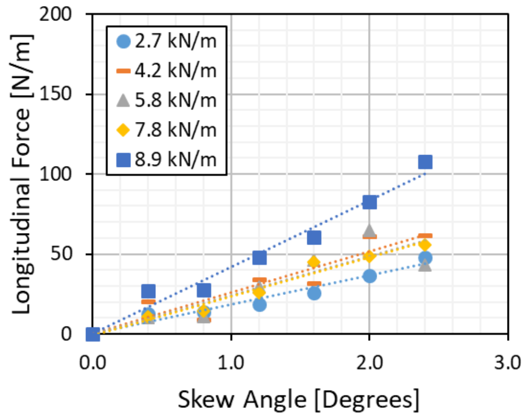
c) Axial force: 1.0 m/s belt velocity



d) Longitudinal force: 1.0 m/s belt velocity

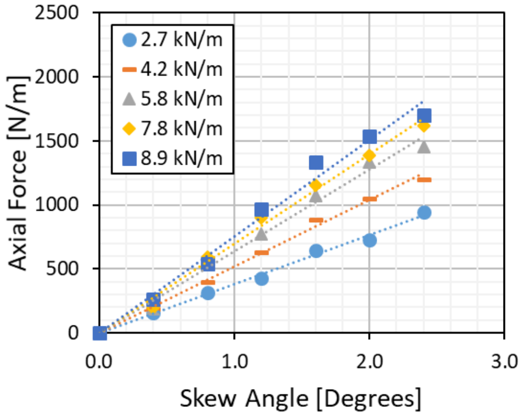


e) Axial force: 1.5 m/s belt velocity

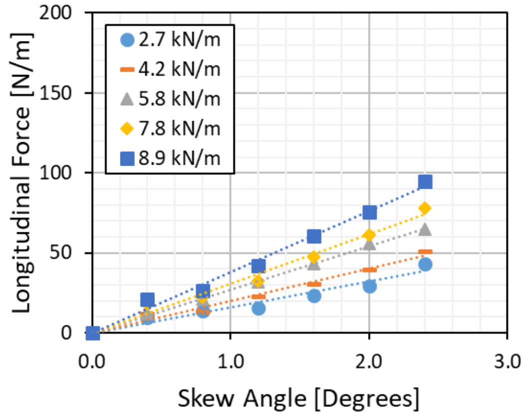


f) Longitudinal force: 1.5 m/s belt velocity

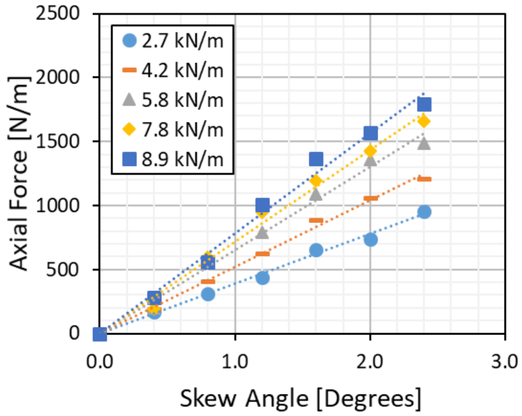
Figure 15. Dynamic measurement results for a ø178 mm mild steel idler roll showing axial and longitudinal forces relative to belt tension



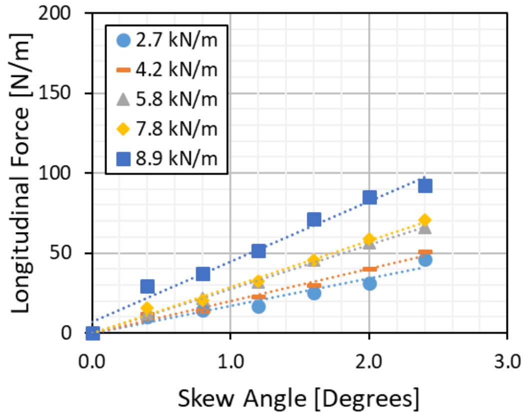
a) Axial force: 0.5 m/s belt velocity



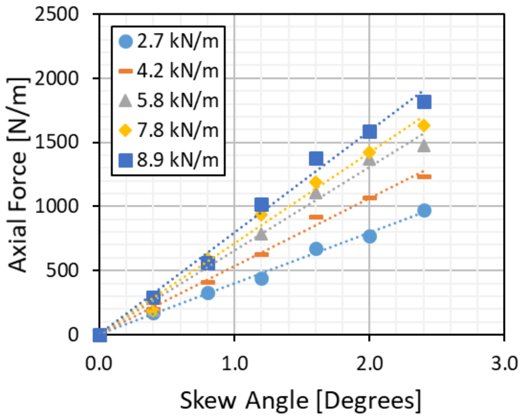
b) Longitudinal force: 0.5 m/s belt velocity



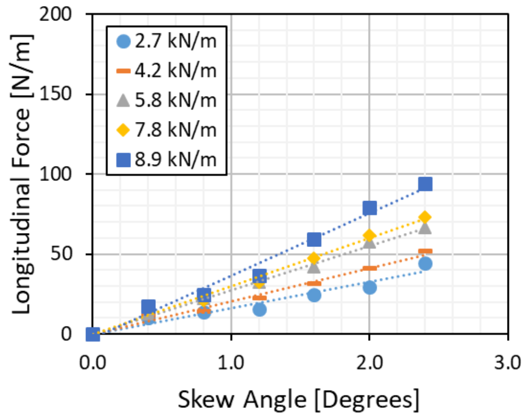
c) Axial force: 1.0 m/s belt velocity



d) Longitudinal force: 1.0 m/s belt velocity

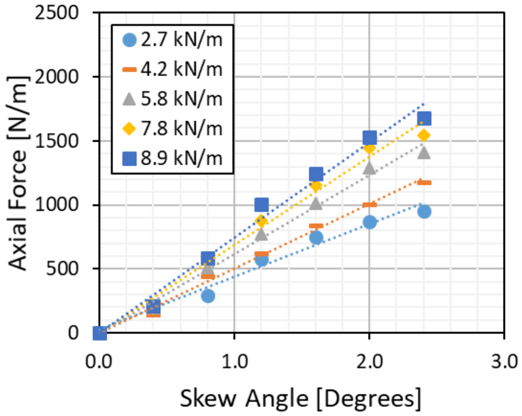


e) Axial force: 1.5 m/s belt velocity

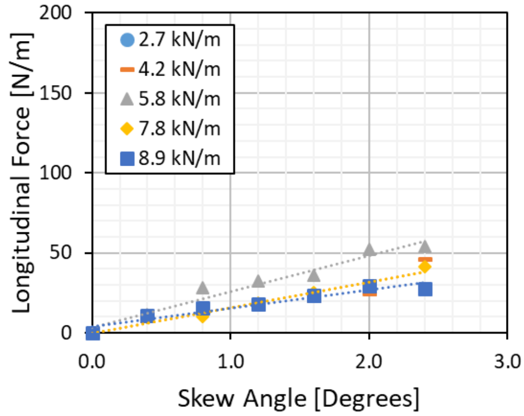


f) Longitudinal force: 1.5 m/s belt velocity

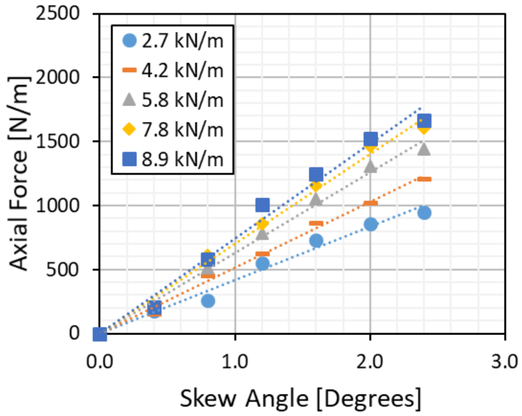
Figure 16. Dynamic measurement results for a ø152 mm PVC idler roll showing axial and longitudinal forces relative to belt tension



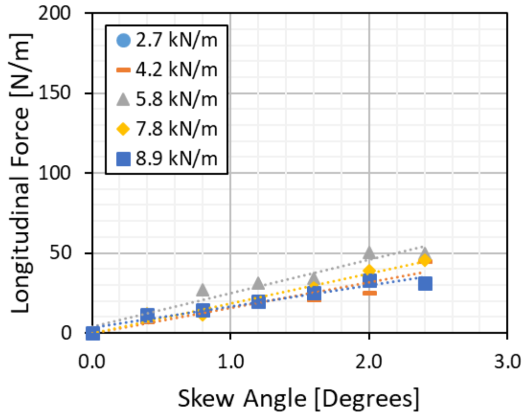
a) Axial force: 0.5 m/s belt velocity



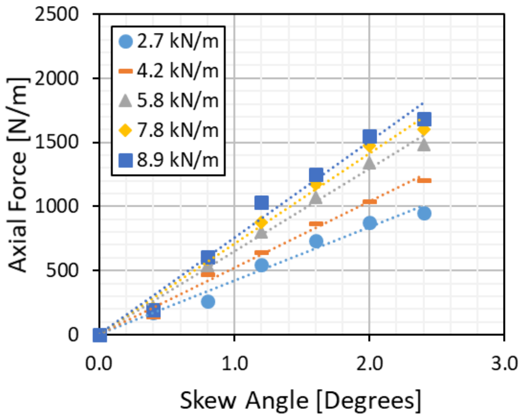
b) Longitudinal force: 0.5 m/s belt velocity



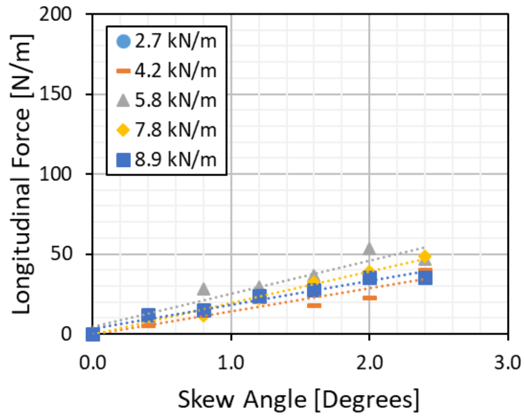
c) Axial force: 1.0 m/s belt velocity



d) Longitudinal force: 1.0 m/s belt velocity



e) Axial force: 1.5 m/s belt velocity



f) Longitudinal force: 1.5 m/s belt velocity

Figure 17. Dynamic measurement results for a ø152 mm HDPE idler roll showing axial and longitudinal forces relative to belt tension

4. RESULTS AND DISCUSSION

The obtained data from the dynamic measurements has been analysed to consider the differences between idler roll diameter and idler roll material for angles of 0.4° up to 2.4° which are undertaken in 0.4° increments. Unlike differences in belt velocities, significant changes to the obtained axial and longitudinal force measurements are attributed to belt tension. Generally, the axial and longitudinal forces increase linearly with idler skew angle, as shown in all testing cases (i.e. Figures 13 – 17). When an increase in belt tension (normal load) is undertaken, the axial and longitudinal force measurements also increase linearly. If the experimental measurement values in the longitudinal direction are compared to the calculated values based on CEMA [2], it can be shown that the measured values are approximately 60% of the calculated values.

When differences in idler roll diameter are considered, a marginal increase of the axial force can be observed, as shown in Figures 13 – 15. This occurs when an equivalent normal load in considered. Additionally, a similar relationship can be observed when the longitudinal force is considered. The increase in acting forces on a larger diameter skewed idler roll can be attributed to the contact area where an increase in area results in additional axial forces.

Similar to an increase in idler roll diameter, when different idler roll materials are considered, a notable increase of the axial force can be observed, as shown in Figures 14, 16 and 17, which is attributed to the increase in friction values as outlined in Figure 8. This occurs when an equivalent normal load is considered. Additionally, a similar relationship can be observed when the longitudinal force is considered. It is appropriate to identify that longitudinal force measurements for the HDPE idler roll for a 2.7 kN/m normal load resulted in a reduction in measurement value with an increase in skew angle. It was therefore deemed appropriate to discount this set of results from the analysis undertaken in Figure 17.

5. CONCLUSIONS

This paper has examined the forces acting on a skewed idler roll for static and dynamic loading scenarios. This was achieved using two test rigs located at the University of Newcastle. The developed testing rigs allowed for measurements of the coefficient of friction and resulting dynamic forces to be quantitatively determined for a range of skewing angles, idler roll materials and diameters. A comparison of analytical investigations and experimental measurements were shown where the prediction of the forces acting on a skewed idler roll in relation to belt mistracking were established.

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