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Technical Article

A descriptive Explanation of the Belt Tracking Properties of Pulleys by using the geometric Properties of the flat Pattern of their Surface

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he direction of a conveyor belt is changed, at pulleys, according to the wrap angle between the pulley and the belt. Compared with idler rollers which just support a conveyor belt, pulleys, due to the wrapping belt, provide different opportunities concerning belt tracking. Due to relatively high belt tensions and wrap angles combined with the according friction factors, pulleys mainly provide static friction to the conveyor belt at the ongoing side [1]. There are different hypotheses available in literature for the explanation of belt tracking and belt misalignment effects concerning pulleys, but apparently none seems to be accepted to be generally valid.

(From the archive of ”bulk solids handling", article published in Vol. 36 (2016) No. 4 , ©2016 bulk-online.com)One hypothesis tries to explain the belt steering effect pulleys apply on conveyor belts by uneven distribution of tension within the belt [2,3,4,5]. A hypothesis concerning crowned pulleys supposes that centrifugal forces within the belt cause a tracking effect [2]. Another hypothesis states that the steering effect pulleys apply to conveyor belts principally relies on bending the belt. The belt is hereby regarded as a bending beam which is laterally bent due to the tilted pulley. The bent belt therefore proceeds by entering the pulley at a certain angle and subsequently wraps itself around the pulley, which is thought to determine the lateral behavior of the belt [6,7,8].

1. Background

According to observations and considerations which the author made during his studies of a specific belt handling problem, geometrical conditions seem to be mainly responsible for the guiding effect, which pulleys apply to conveyor belts. A descriptive, mainly geometrical explanation of the lateral behaviour of a conveyor belt at pulleys shall hereby be given. With this, the actual angle between a pulley and the belt, combined with the dynamically varying radius of curvature of the centre line of the laterally bent belt, observed at the boundary line between the belt and the pulley are used. This explanation mainly uses the projection of the geometry of the centerline of a belt, which wraps itself around a pulley, while the flat pattern view of that pulley provides a descriptive overview of the driving mechanisms of belt tracking.The pulley shall be regarded, for simplification reasons either as a cylinder or as a cone and a certain friction force between the pulley and the belt is presumed to exist due to belt tension together with a certain wrap angle, combined with a certain friction factor [1]. In addition, the belt shall be regarded as an elastic bending beam [6].The angle between the pulley and the conveyor belt, combined with the actual radius of curvature of the centre line of the conveyor belt, observed at the ongoing boundary line between the pulley and the belt, then drive the lateral behaviour of the running belt. The geometrical characteristics of the belt along a pulley, and before that pulley, combined with friction between the pulley and the belt, cause the belt to run onto the pulley at a distinct lateral direction, which is then stuck by friction. If the belt proceeds running onto that pulley, it is dynamically guided towards a certain lateral position.For simplification purposes a belt which is hypothetically wrapped 360° around a pulley and without a gap between the two should be investigated, the belt entering the pulley at any reasonable lateral position and at any reasonably desired angle. The wrap angle of 360° theoretically makes the belt run across the whole flat pattern of the pulley at one moment. If other wrap angles or belt running distances should accordingly be regarded, corresponding positions at the pulley and its flat pattern have to be considered.

2. Cylindrical Pulleys which are tilted relatively to the Belt running Direction

In the case of tilting a cylindrical pulley, the turning axis of the pulley shall be tilted at a certain angle relative to the main longitudinal direction of the conveyor belt. It is known that the running belt then deviates towards the side which is closer to the tilted pulley.If the mantle surface of a cylinder is shown as a flat pattern, it can be seen that this flat pattern can have the shape of a rectangle. For the following considerations the belt should first enter the pulley directly at a junction line of the rectangular flat pattern of a cylindrical pulley (Fig. 1).

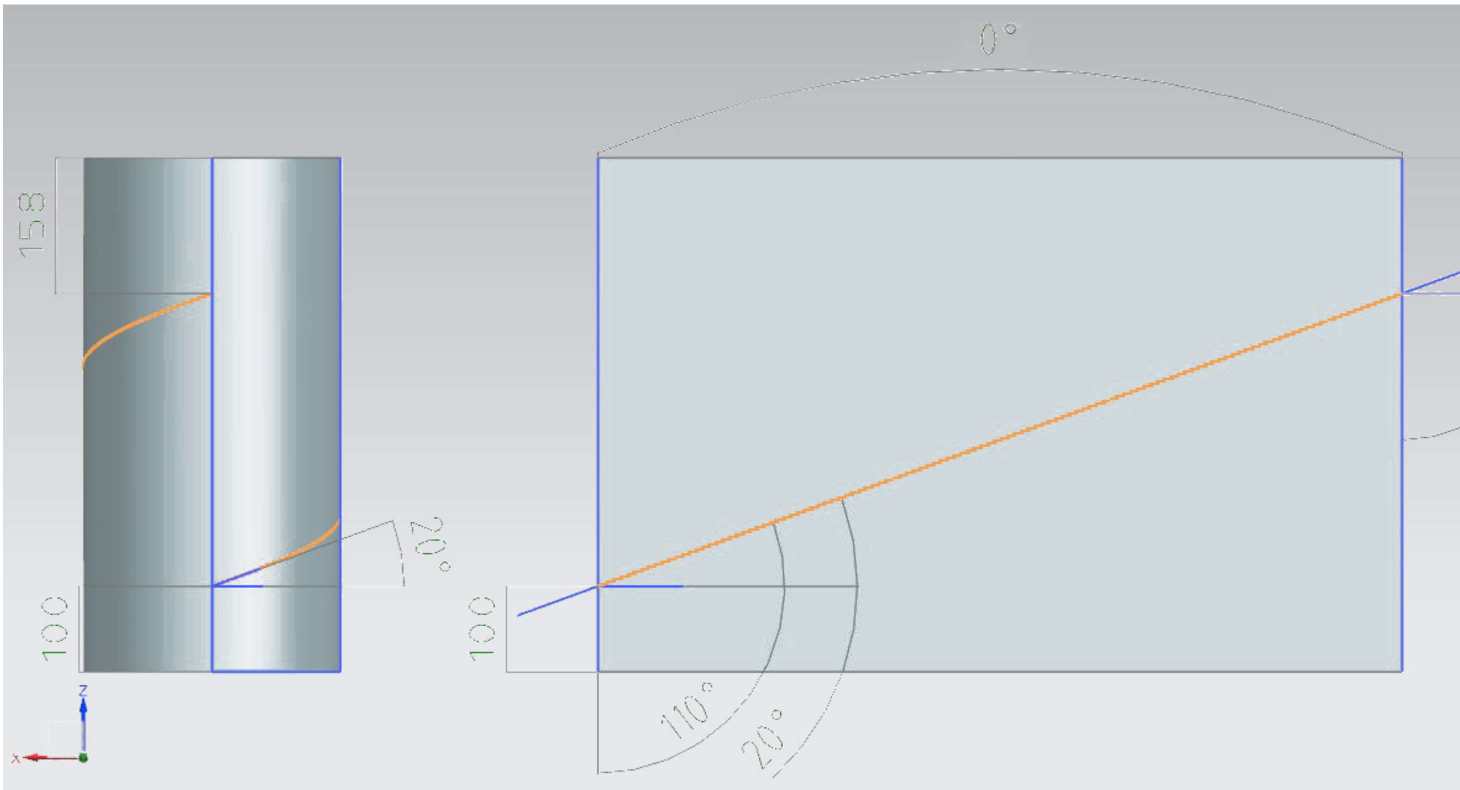

Fig. 1: Images showing the side and 3D view of a cylinder with the flat pattern of its mantle surface and a laterally unbent line across it. (Pictures: © G.A. Kribitz)

For the first step the belt should wrap around the cylinder but should not be laterally bent. Accordingly, the track of its longitudinal centerline, which is schematically simplified as a line, can be projected to the unrolled flat pattern of the cylinder, which is then a flat rectangle. That centerline always appears as a straight line. This straight geometry demonstrates that a belt can obviously be wrapped around a cylinder, with neither a gap between them nor a lateral deformation, simply by bending around the cylinder.The straight centerline of the laterally straight belt always enters and leaves the junction lines of the flat pattern of the cylinder at the same relative angular direction, because the junction lines are located parallel to each other (Fig. 2).

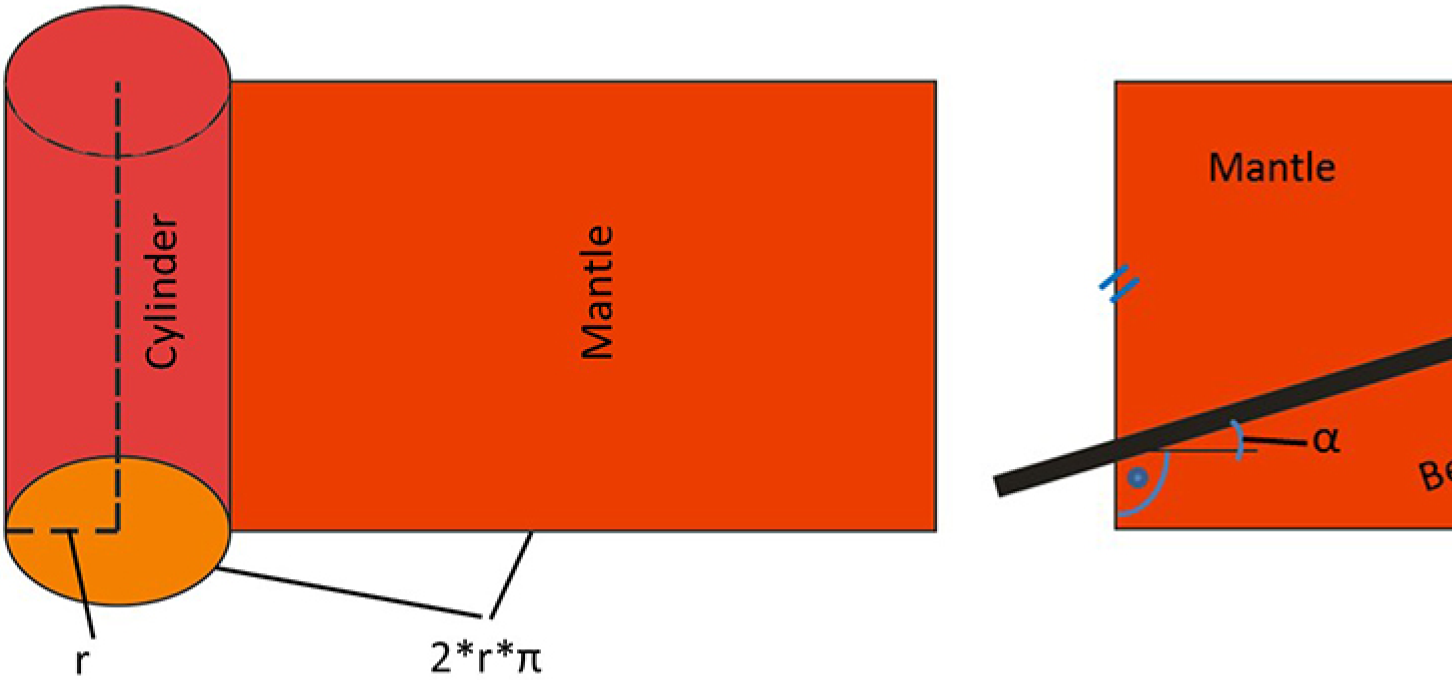

Fig. 2: Images with schematic sketches showing the geometry of a cylinder with the flat pattern of its rectangular mantle surface (left) and the centerline of a straight belt across the mantle of a cylinder (right).

Only if the angle of that belt, seen at the entry boundary - line between the belt and the cylinder, is permanently exactly perpendicular to the junction line of the cylinder, the belt wraps around the cylinder along a constant lateral position (Fig. 3).

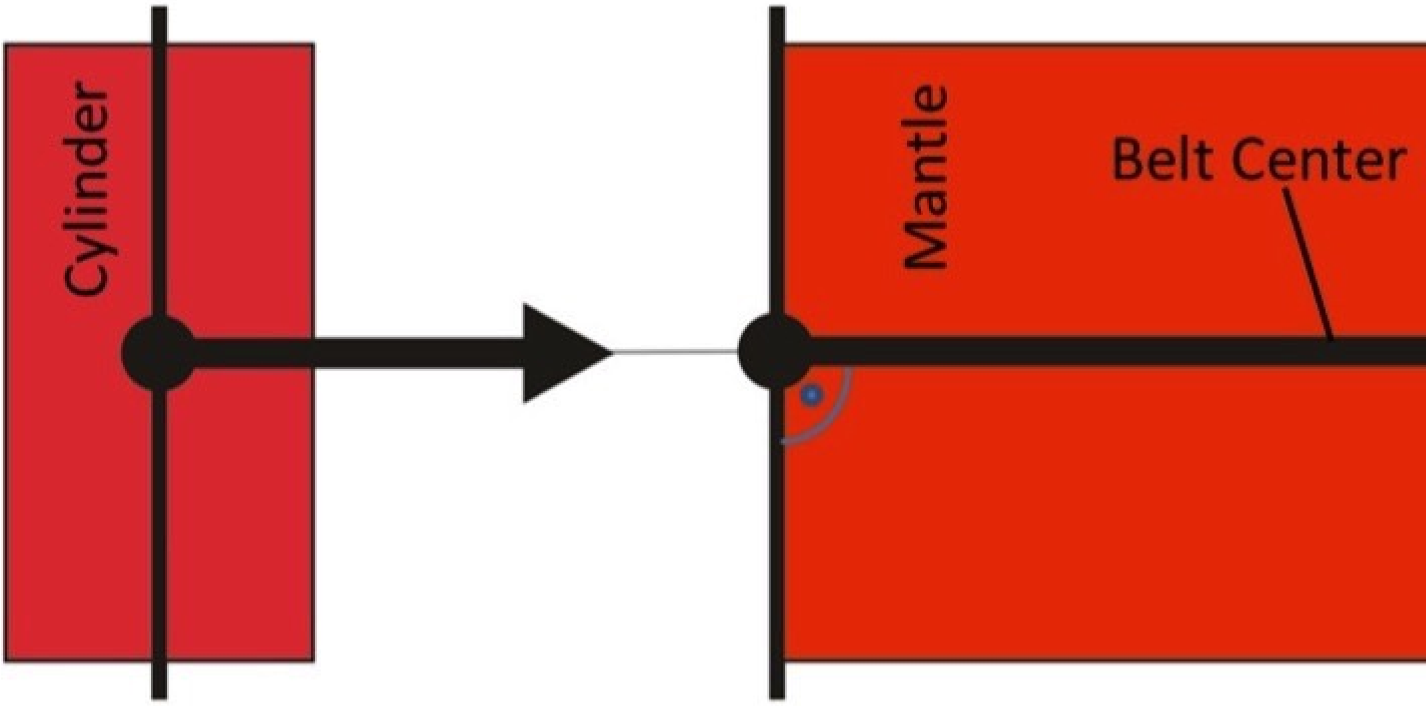

Fig. 3: Centerline of a straight belt across the mantle of a cylinder along a constant lateral position.

If a belt, seen at the entry boundary - line between the belt and the cylinder, is angled in a certain direction to the perpendicular direction of the junction line of the cylinder, the belt wraps itself in this angled direction. As soon as the centerline of the laterally straight belt is inclined to the perpendicular direction of the junction line of the flat pattern, the belt will wind around the cylinder along the track of a helix with constant pitch. If a laterally straight belt runs onto a somewhat tilted cylinder, it can be seen at the flat pattern view that following belt sections will move laterally towards the closer end of the cylinder (Fig. 4).

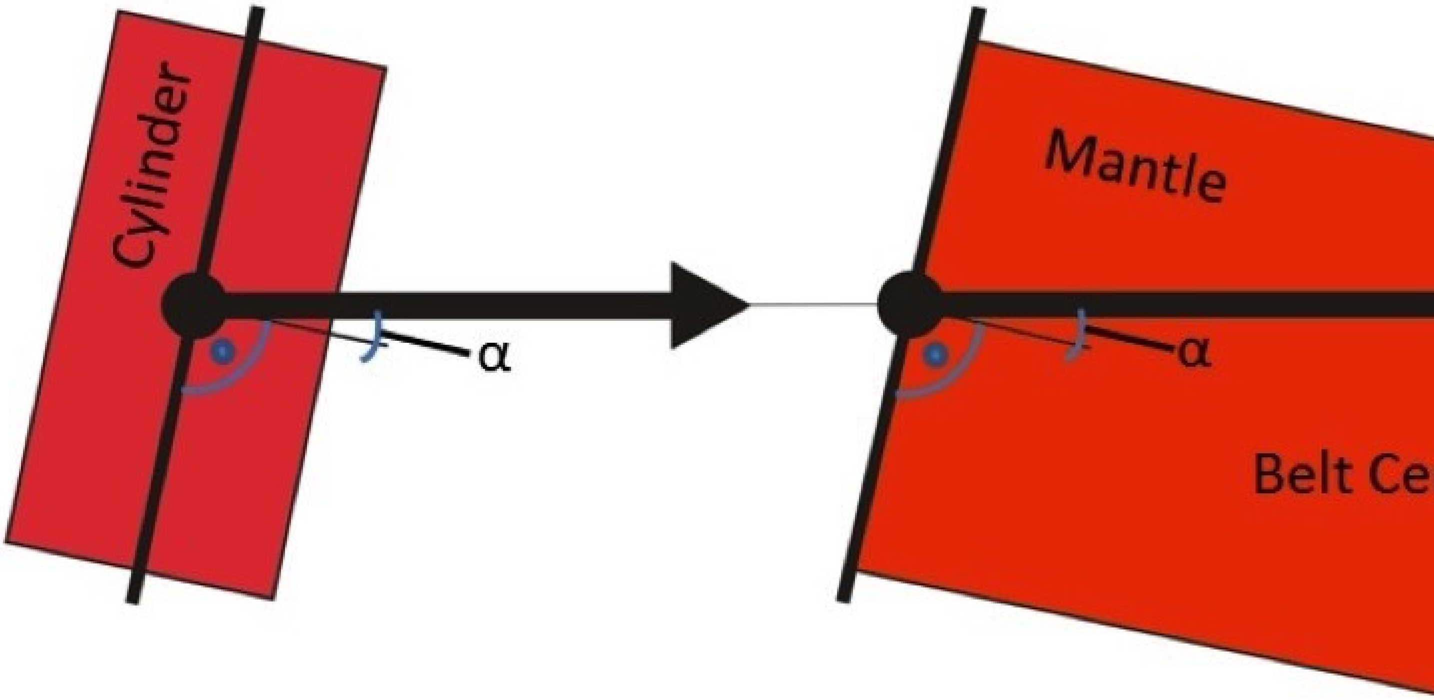

Fig. 4: Centerline of a straight belt across the mantle of a cylinder, while the axis of the cylinder is tilted with respect to the centre line of the belt.

If now a belt is already wrapped around a cylinder which is not rotating along a straight line in the flat pattern view of that cylinder, and if the position of the opposite end of that belt is changed laterally, the belt is bent from the cylinder towards its deviated end along the arc of a distinct lateral deflection curve. Accordingly the centerline of the belt is located along two different segments. The first segment is wrapped around the cylinder with friction between them. The second segment is the free hanging, laterally bending segment between the tangent line and the laterally deviated end of the belt (Fig. 5).

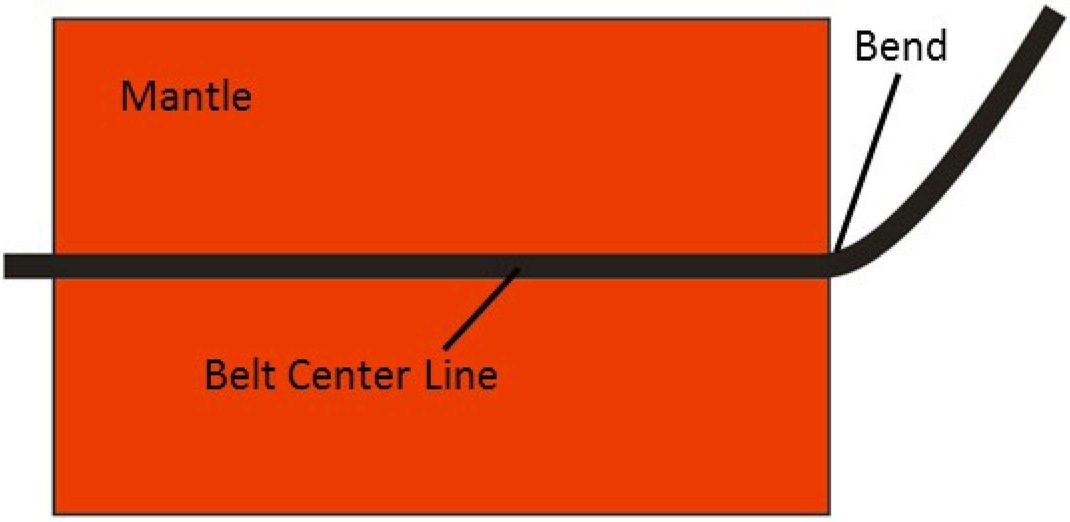

Fig. 5: Mantle of a cylinder with a
straight belt stuck at it and with a
subsequent laterally bent belt.

For simplification purposes, it shall be assumed that at the beginning of the case described in the following, the centerline of the belt is directed parallel to an arbitrary but constant diameter of a rotating cylinder and therefore the belt shall be running along a constant lateral position. If however the location of the opposing end of the belt is suddenly being laterally misaligned, the free hanging part of the belt will be bent laterally towards its deviated opposing end. If a running belt is laterally bent, the angle between the pulley and the belt at the ongoing boundary line is dynamically influenced by the actual shape of the curve of this bend [6,7]. This also indicates that additional belt will be wrapped laterally deviated.If the misaligned belt is being wrapped around the cylinder, due to the deviation caused by the bent arc, the center line of the belt is no longer perpendicular to the theoretical junction line of the cylinder but deviated angularly towards the deviated opposing end. The wrap direction of subsequent belt is determined by the actual angle at the boundary line, while the dynamic behavior of that angle and the actual lateral position of the boundary line are determined by the dynamic behavior of the lateral deflection curve of the belt. Then subsequent portions of the belt will also stick to the cylinder along the boundary line due to friction, keeping their laterally and angularly deviated geometry, while again subsequent portions of the belt will follow in a comparable way.Therefore the direction of the already stuck belt, seen directly at the junction line, continuously changes its direction, which together with the position of the opposed deviated end of the belt, has an impact on the shape of the laterally bending arc. This dynamic change of the shape of the bending arc causes the belt to be subsequently wrapped around the cylinder along the shape of a helix with a variable pitch (Fig. 6). If the belt at the beginning of this case was already running along the track of a helix, and not along a constant lateral position, lateral deviations of the opposing end would have a comparable influence. For geometrical reasons a laterally deviated opposing end of the belt and a tilted pulley will have a comparable influence on the behavior of a running belt.

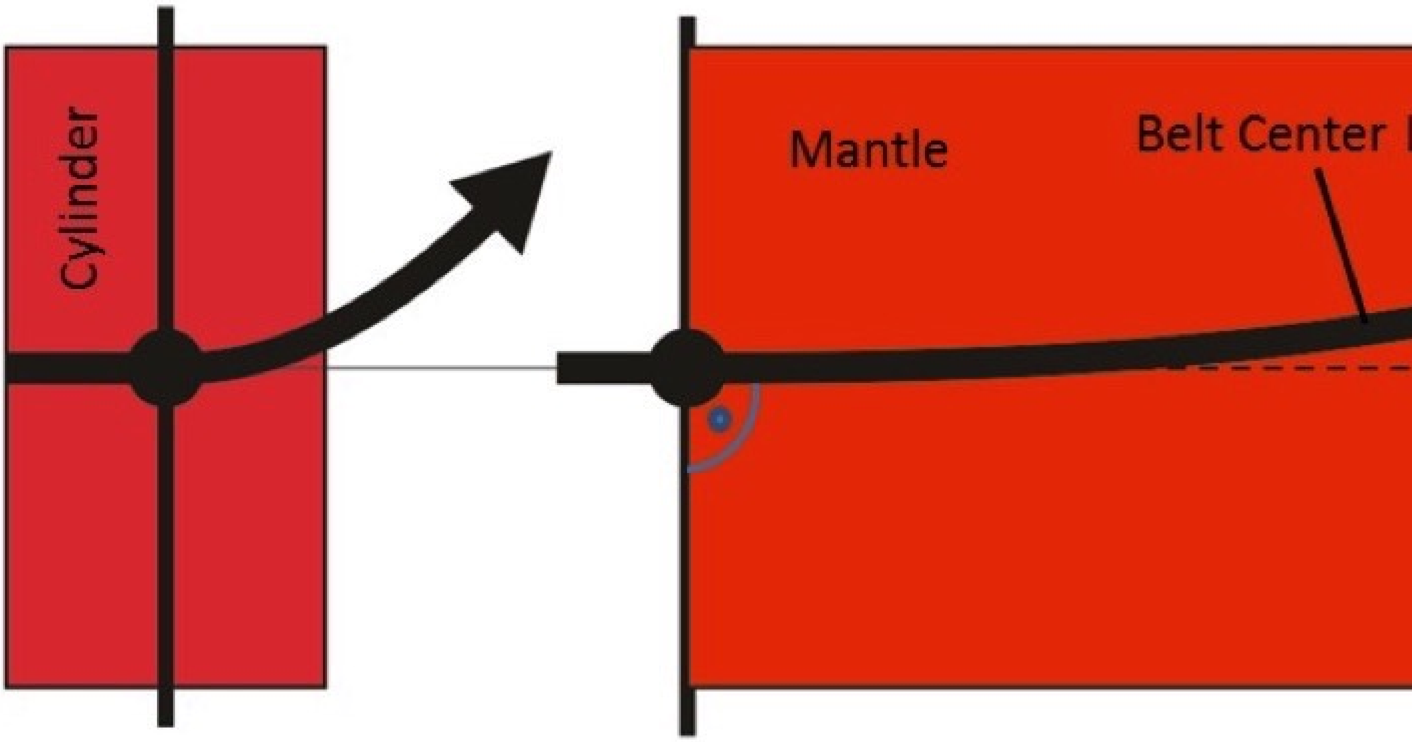

Fig. 6: Flat pattern of the mantle of a cylinder, with a belt dynamically wrapped around the cylinder from a straight and perpendicular start position (point) but with a laterally deviated opposing end.

3. Crowned Pulleys

For a long time now crowned pulleys have been used to keep belts centred. There are many existing different types of crowned pulley, including pulleys with a trapezoid outline, with a spherical outline or other (Fig. 7), but their common feature is that their central diameter is bigger than the diameter at the rims [5,9]. For further considerations a single straight cone, resembling one half side of a symmetrical conic crowned pulley, is used.

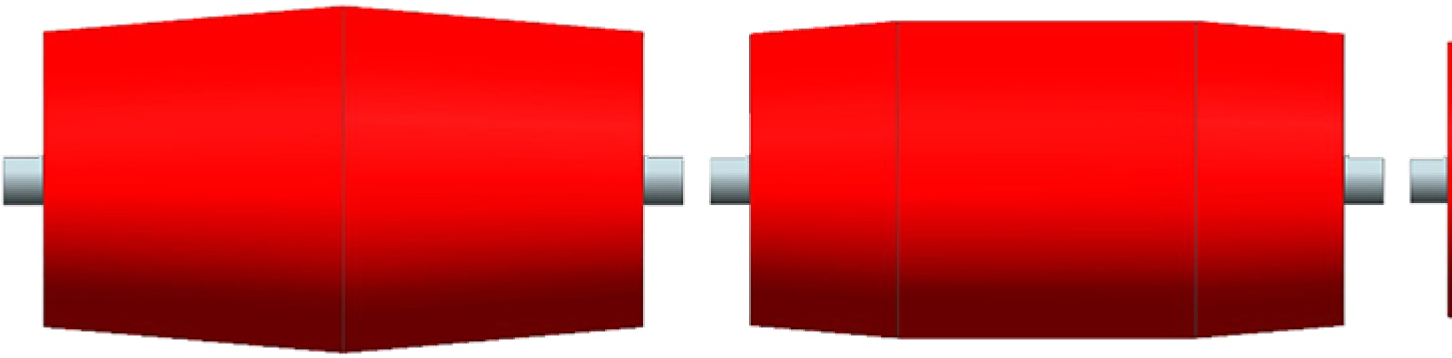

Fig. 7: Images show different types of crowned pulley (the crowning is highly exaggerated for visualization purposes): A pulley with a double symmetric conic crowning (left), a trapezoid crowning (middle) and a circular crowning (right).

If the mantle surface of a cone is shown as a flat pattern, it can be seen that this flat pattern has the shape of a circular sector. (Figs. 8, 9).

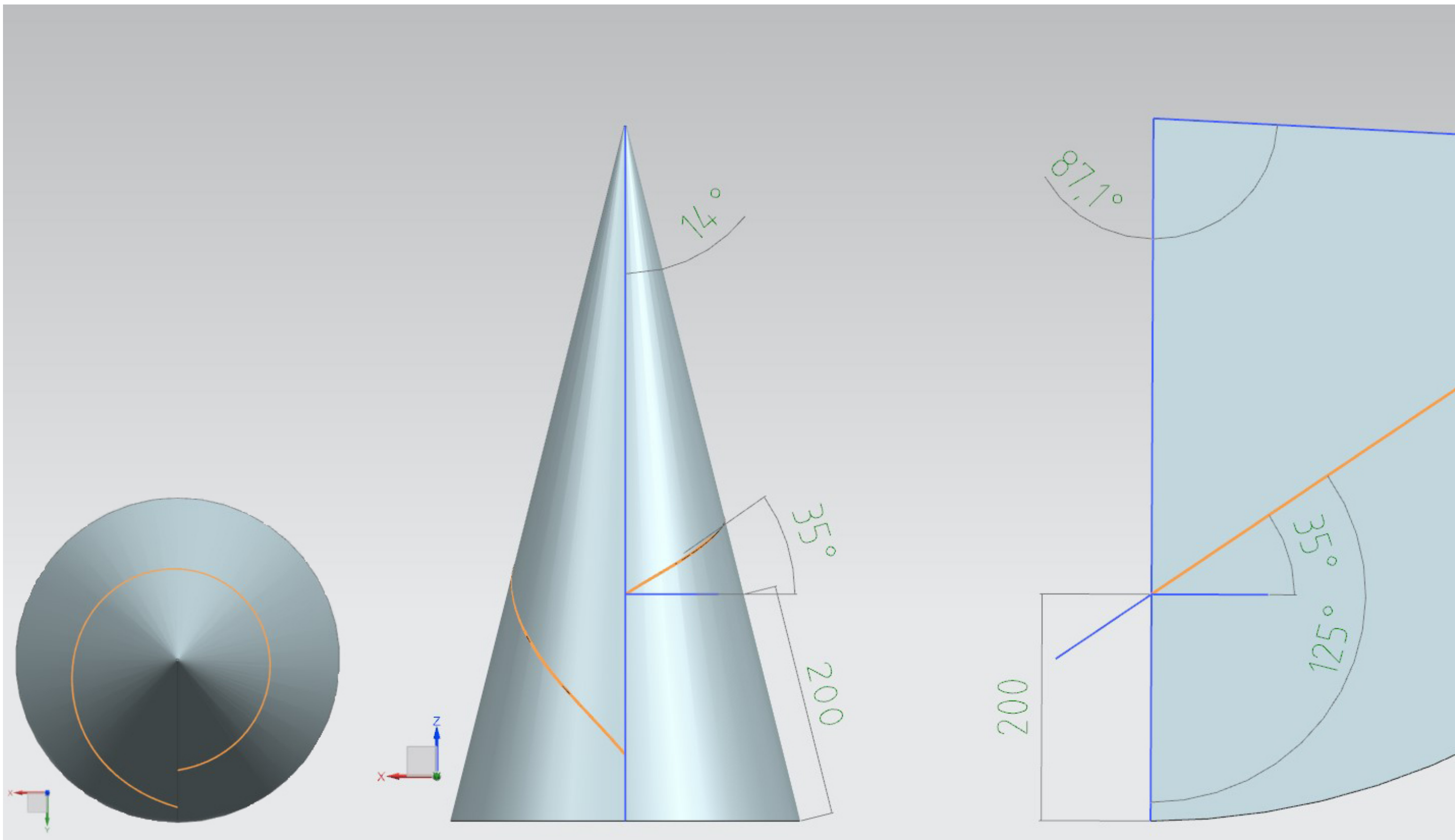

Fig. 8: 3D image showing the top and side views of a straight cone with the flat pattern of its mantle surface and a laterally unbent line across the surface of the cone.

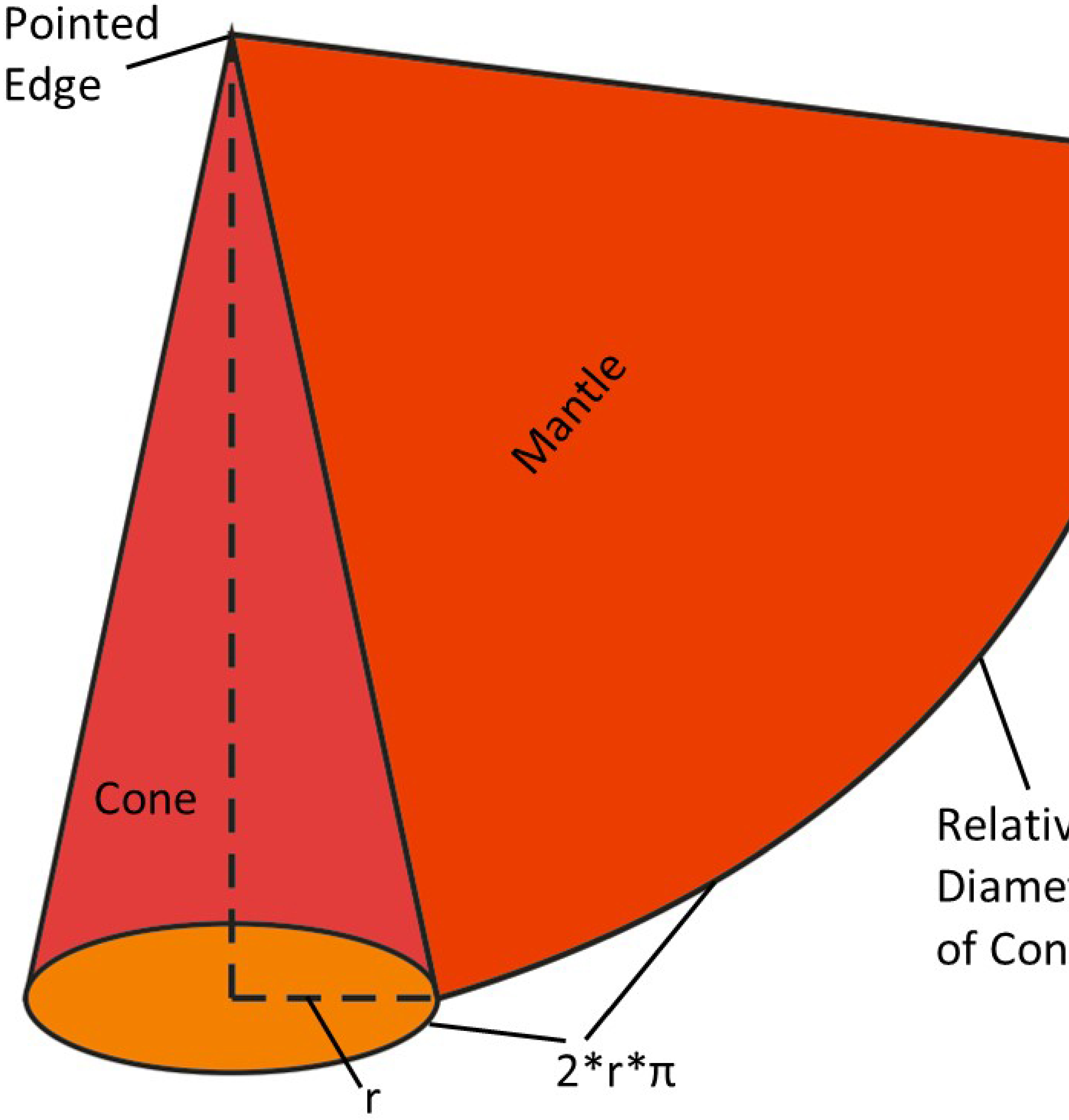

Fig. 9: Geometrical conditions of the flat pattern of the mantle surface of a cone, which has the shape os a circular sector.

For the first step a belt should wrap around the cone but laterally it should not be bent. Accordingly, the track of the longitudinal centerline of this belt, which is schematically simplified as a line, can be projected to the unrolled flat pattern of the cone, which is a flat circular sector. The centerline always appears as a straight line.It can be seen that the straight centre line of the belt enters the circular sector of the flat pattern of the cone at a different relative angle from that as it leaves it. This is because the junction lines are connected to each other at a pointed edge, showing a distinct central angle.

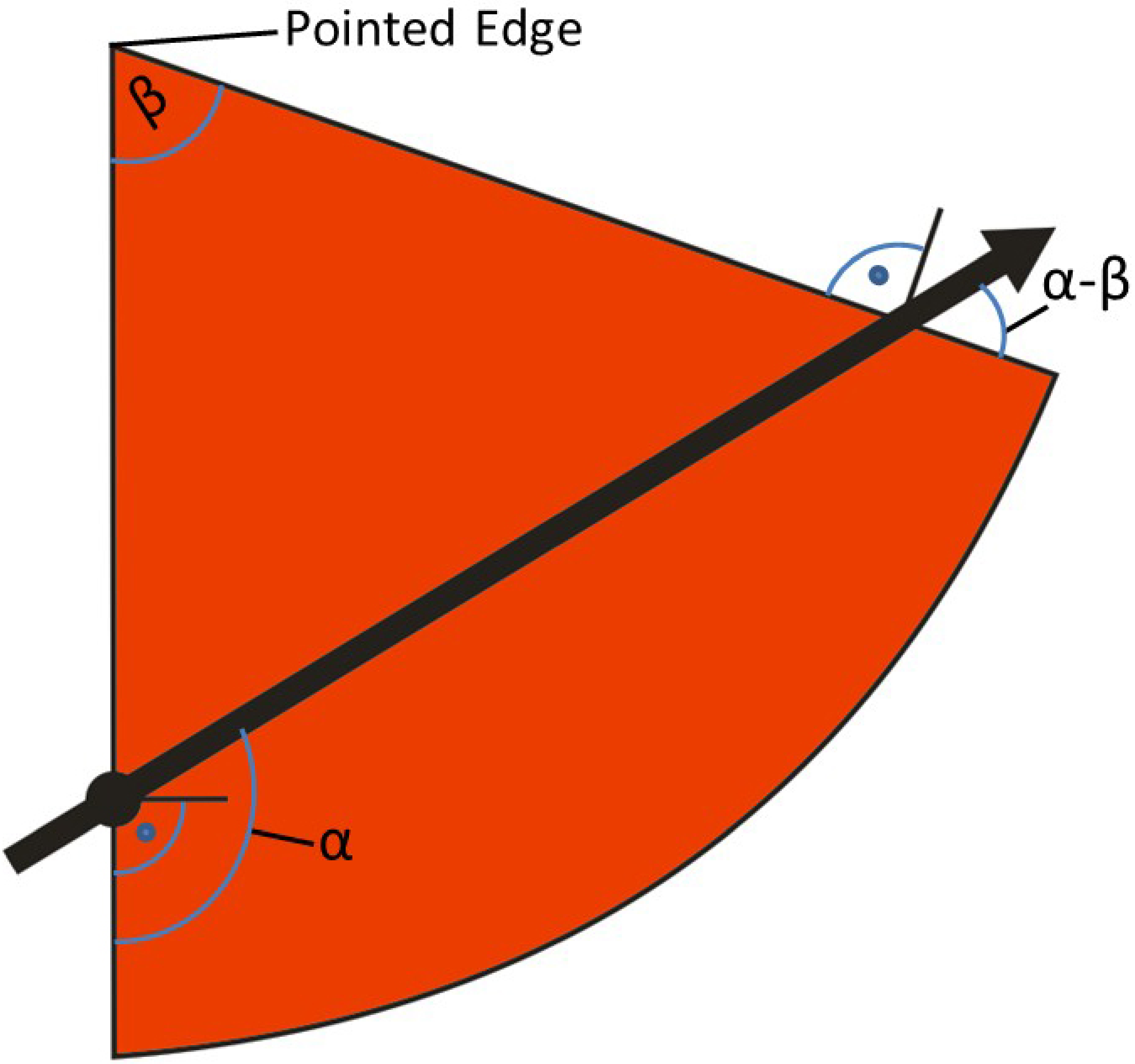

Fig. 10: centerline of a straight belt across the flat pattern of the mantle of a cone. The belt is always deviated relatively to bigger diameters, according to the junction lines of the flat pattern.

Due to the central angle between the junction lines of the circular sector, compared to the ingoing junction line, at the outgoing junction line the projected centre line of the belt is directed by the degree of that central angle towards bigger diameters of the cone (Fig. 10).If a belt first touches a cone along its junction line perpendicularly to that junction line, the straight centre line of the belt leaves the circular sector of the flat pattern of the cone clearly deviated towards a relatively bigger diameter of that cone (Fig. 11).

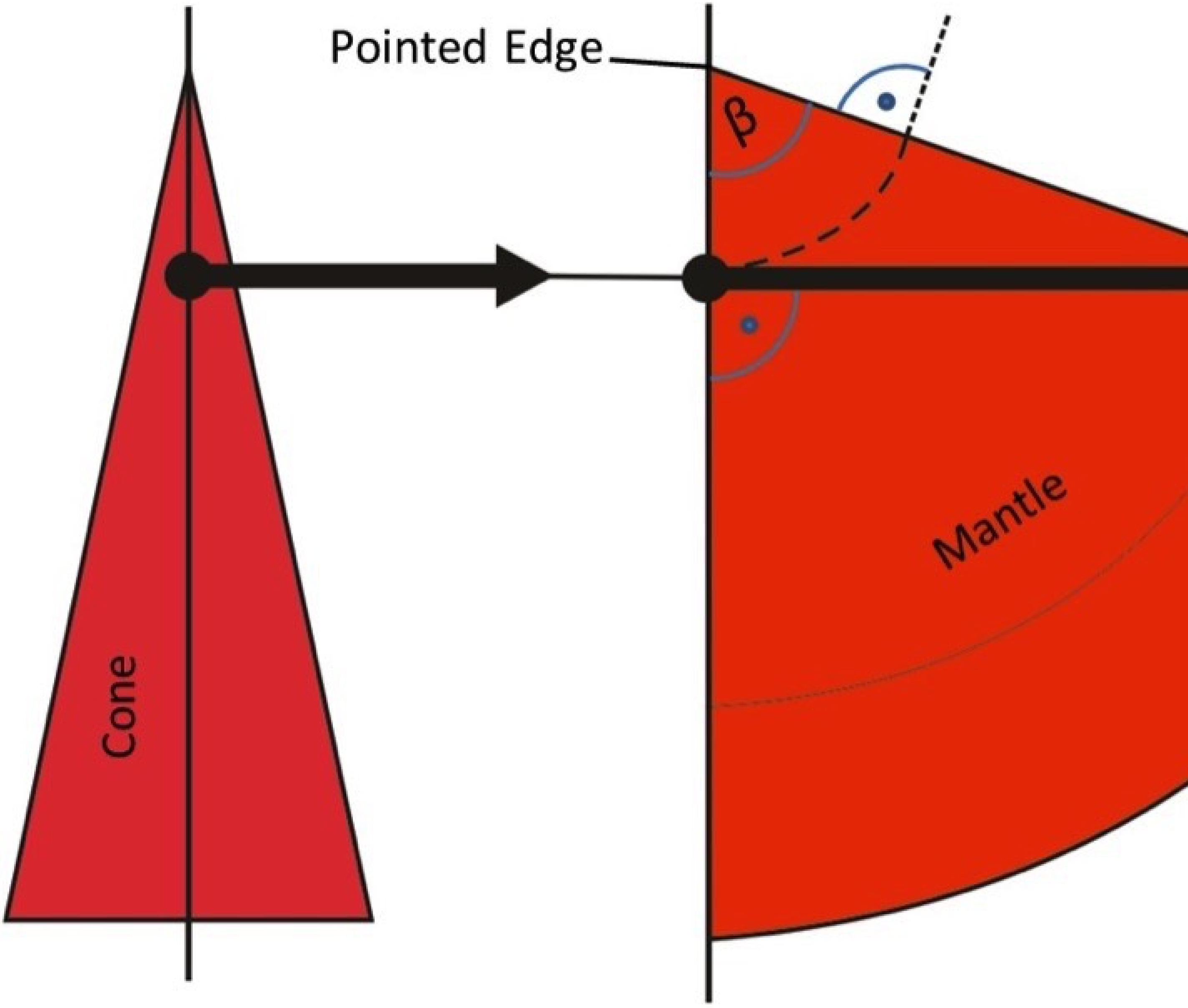

Fig. 11: Centerline of a straight belt across the flat pattern of the mantle of a cone. The belt is always deviated relatively to bigger diameters, according to the junction lines of the flat pattern.

If a belt first touches a cone along its junction line, even when angled towards its pointed edge, the straight centre line of the belt leaves the circular sector of the flat pattern of the cone still clearly deviated towards a relatively bigger diameter of that cone (Fig. 12).

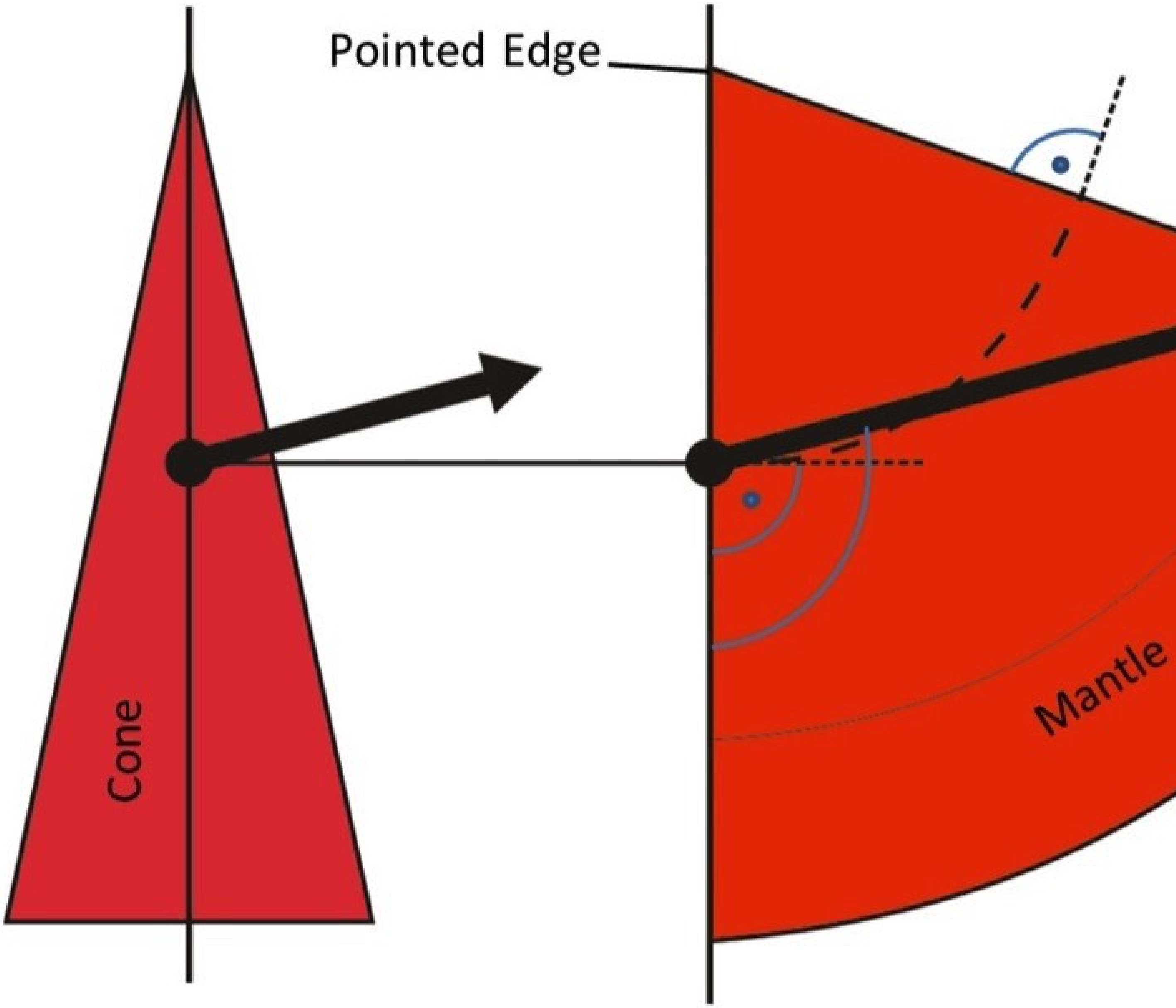

Fig. 12: Centerline of a straight belt first touching the flat pattern of the mantle of a cone directly at a junction line with an arbitrary angle, inclined towards the pointed edge (point). If the cone is now rotated, the laterally undeformed belt will wrap (direction indicated by the arrow) along the cone towards a relatively bigger diameter of

that cone.

The angle between a crowned pulley and a belt at the ongoing boundary line is influenced by the shape of the curve of this bent belt [6,7,8].As known from practical observations, a belt can also run around a cone at a constant lateral position in a steady state movement. Based on my own observations and on geometrical considerations, the belt has then to be deformed by bending, or gaps between the belt and the cone will occur at the relatively smaller diameter of the cone or a combination of both will occur.

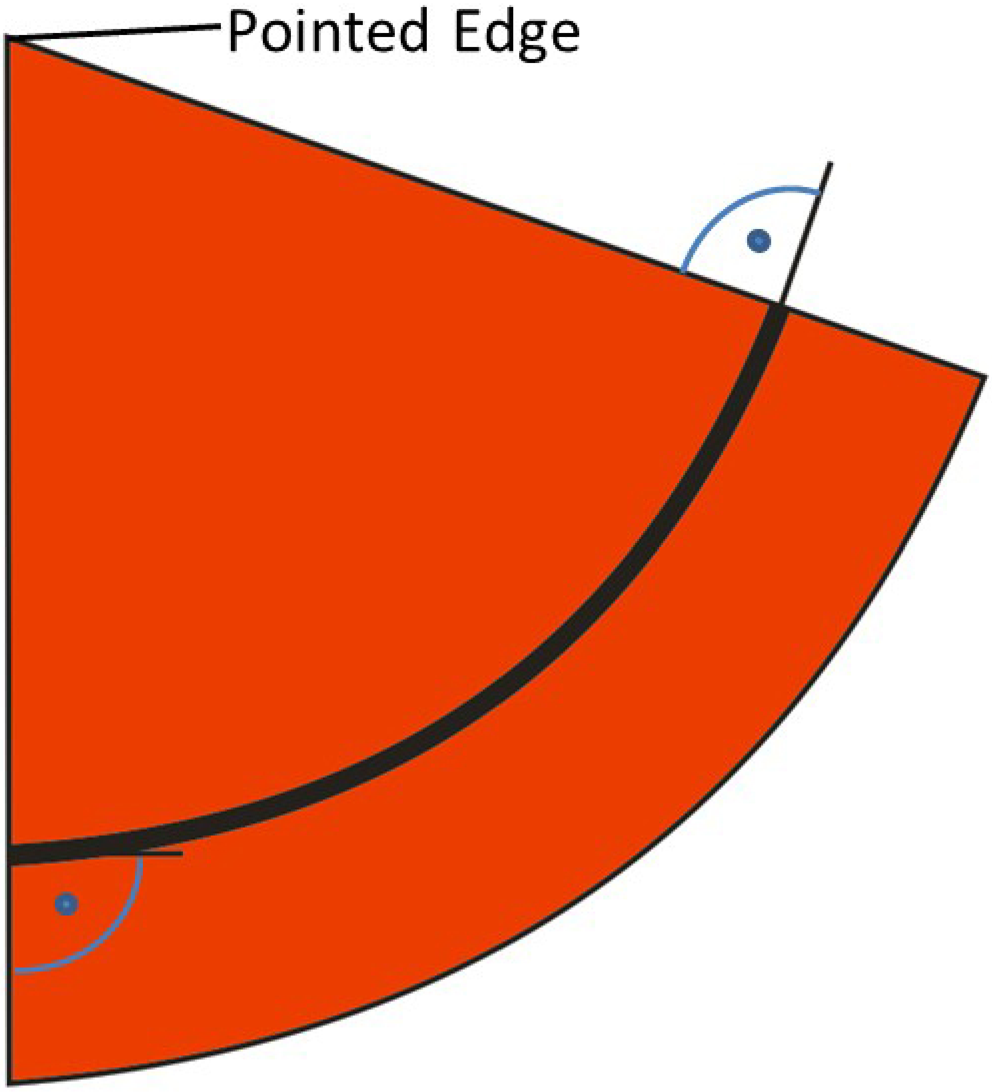

Fig. 13: Circular sector, resembling the flat pattern of the mantle of a cone, with the centerline of a belt being bent along a constant radius, with respect to a constant lateral position of the cone.

It shall be presumed that the belt wraps around a cone without gaps between the two. Geometrically an arc of a cycle, which is positioned onto the flat pattern of a cone, while the center of this arc of a cycle is positioned exactly concentric to the center of the circular sector of the flat pattern of the cone, resembles a bent belt which is located along a constant lateral position of the cone (Fig. 13). Therefore, if a belt is wrapped around an arbitrary, but constant diameter of a cone, without leaving gaps between the belt and that cone, the belt has to be bent around that cone and it has additionally to be laterally bent.The next step is examining a belt which is running around a cone along a constant lateral position. Then, at the area of the boundary line between the belt and the cone, namely exactly at the position where the friction between the belt and the cone reaches the amount of static friction, the geometry of how this belt has to be bent laterally, has to match the arc of a cycle, which describes a constant lateral position on the flat pattern of the cone. Thereby the centerline of the belt has to be permanently perpendicular to the actual junction line of the flat pattern of the cone (Fig. 14).

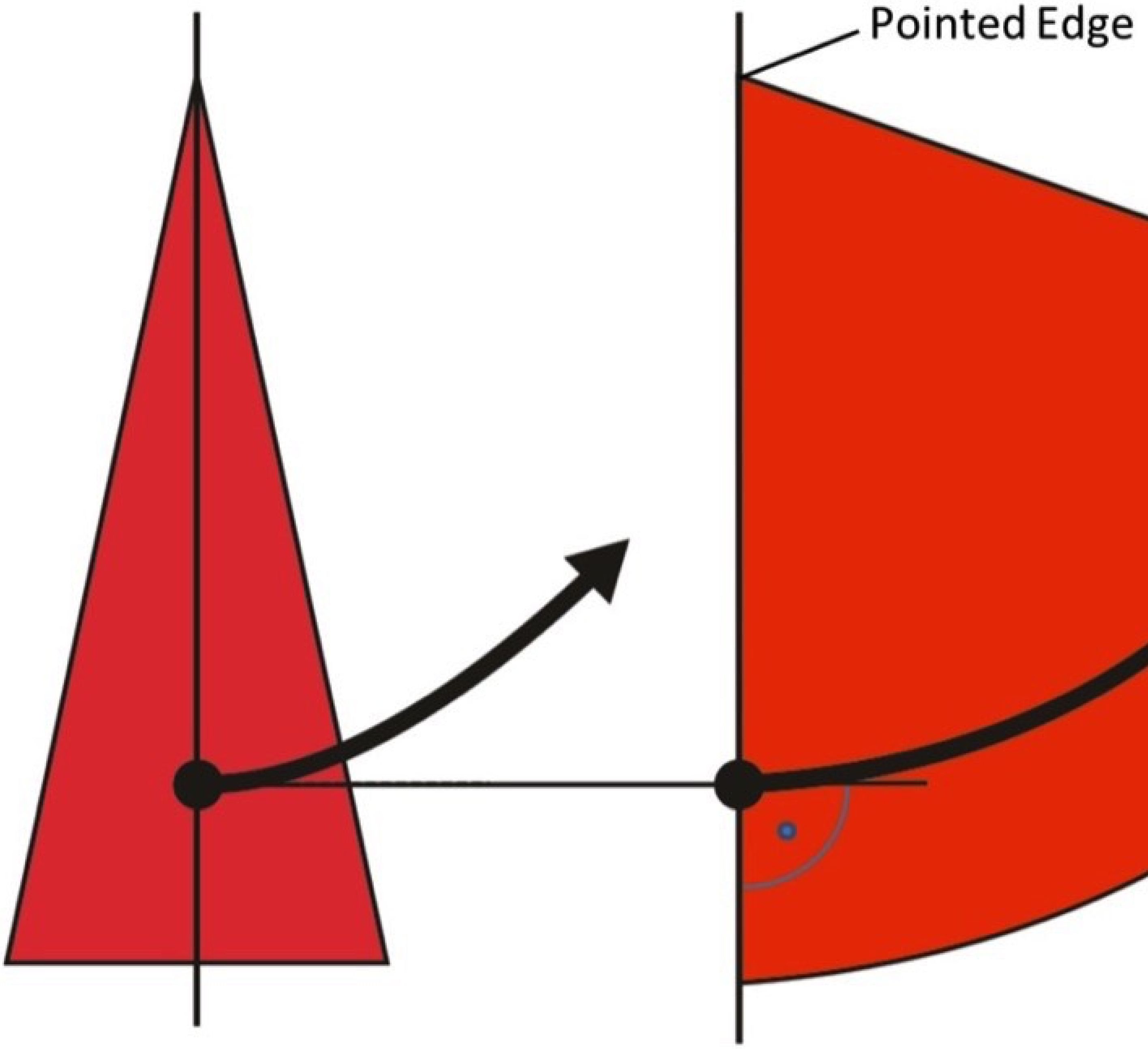

Fig. 14: Centerline of a belt being bent along a constant radius, across the flat pattern of the mantle of a cone, with the belt starting at the ongoing side of the cone (point). If the radius of the belt along the cone is constant, the belt will run around the cone in a steady state movement, along a constant lateral position (direction indicated by the arrow).

Therefore, if a belt runs exactly along a constant diameter of a cone, equilibrium between the centering ability of the cone and the deviated position of the opposing end of the belt or the angular misalignment of the cone respectively, is achieved. If this equilibrium deviation of the belt or the corresponding equilibrium of angular misalignment of the cone is neglected and increased or decreased accordingly, also the radius of the bending arc of the center line of the belt, regarded at the boundary point between the belt and the cone, is increased or decreased. Accordingly the belt would no longer maintain a constant lateral position but it would run towards a smaller or a bigger diameter of the cone.This means that a cone or a crowned pulley, regarded at a certain diameter, is able to hold a laterally deviated belt towards relatively bigger diameters of the cone up to a certain, limiting degree. At this limiting situation, the radius of the arc of the center line of the laterally bent belt, regarded exactly at the boundary line where the belt is stuck by static friction to the pulley, is equal to the radius of the arc of a circle, which describes the laterally constant position on the flat pattern of the cone.It can be seen, that for guiding a belt towards relatively bigger diameters of a conical pulley, advantageous conditions are given, if the position regarded on the cone shows a relatively smaller radius on the flat pattern of the cone, than the bending arc of the centerline of the belt.

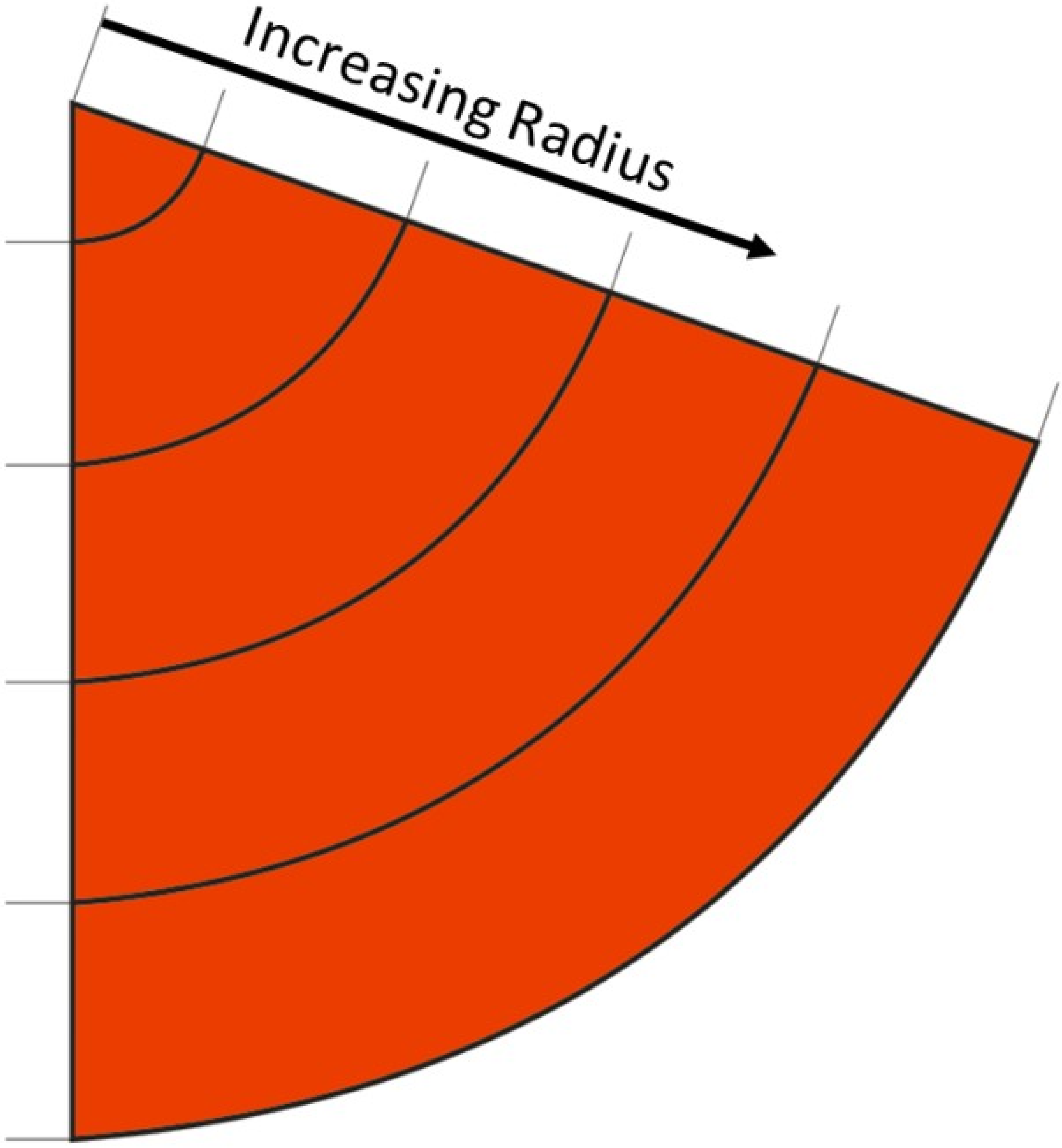

Fig. 15: Arcs of a cycle with different radii, located concentrically with a circular sector.

The radius of an arc of a circle which is concentric with a circular sector varies depending on its location on that circular sector. Small radii of that arc of a circle indicate a location relatively close to the pointed edge of the circular sector (Fig. 15). This geometrical property is valid independent of the central angle of that circular sector and the corresponding cone.In the following, straight cones with different central angles are investigated. If different types of cone shall be compared concerning belt guiding capacity, for practical and for standardisation reasons, these cones have to be regarded at equal diameters, involving also equal perimeters at these lateral positions. If an arc of a cycle with a distinct length is positioned concentrically onto a circular sector, this arc of a cycle is determined by a distinct radius. Then the length of that arc of a cycle correlates to the perimeter of the corresponding cone at that specific lateral position. If an arc of a cycle with equal length is put onto a circular sector with a relatively smaller central angle, the radius, which determines the arc of a cycle will be relatively bigger. This means that cones with a relatively big central angle provide a relatively small radius for an arc of a cycle with a distinct length, when this arc of a cycle is located concentrically onto the circular sector of the flat pattern of that cone (Fig. 16). Therefore, as far as conical pulleys are concerned, either cones with a relatively weakly pointed edge, or positions along relatively smaller diameters on cones, or a combination of these conditions is generally advantageous for belt guiding effects towards bigger diameters.

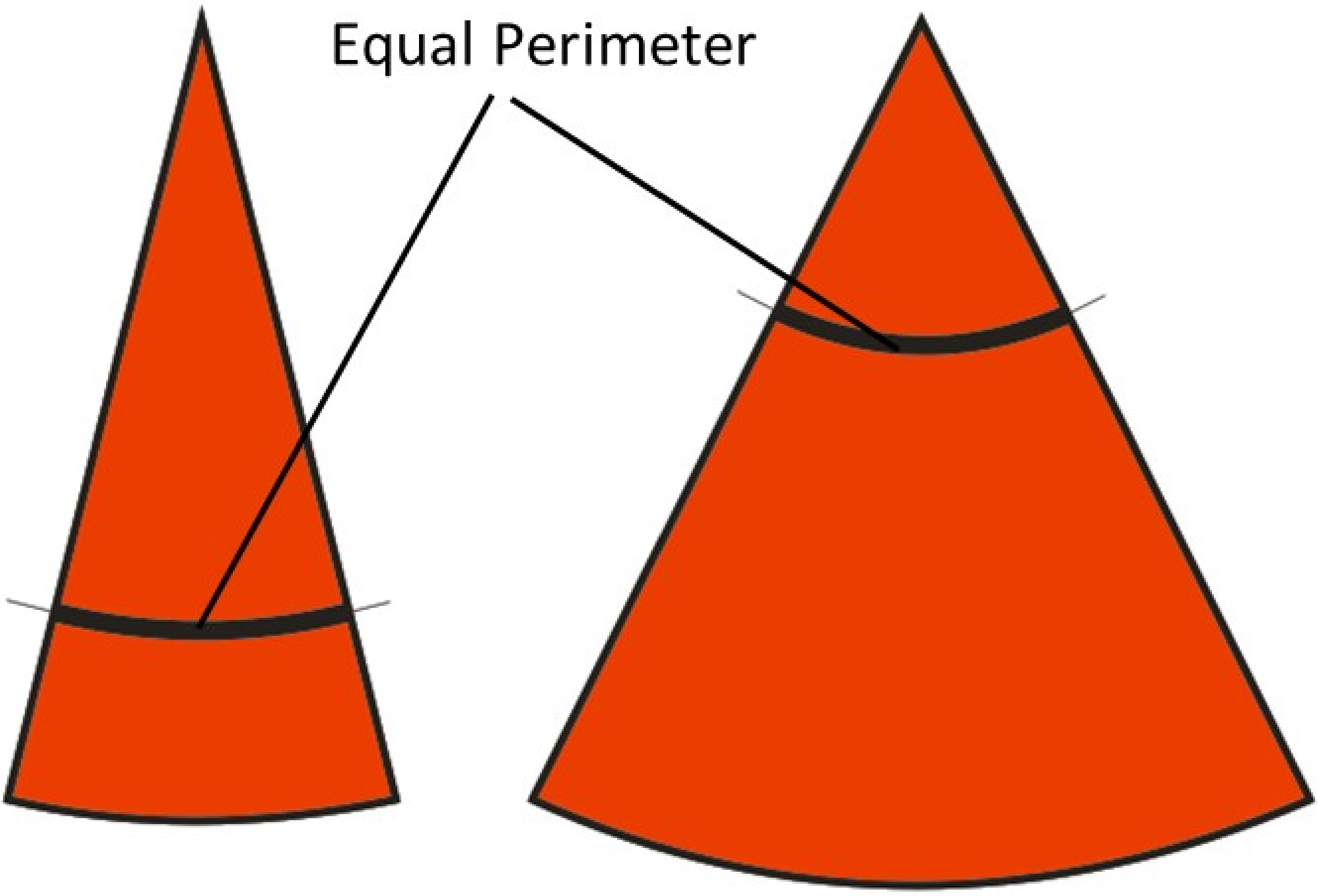

Fig. 16: Flat patterns of a relatively strongly pointed cone (left) and of a relatively less pointed cone (right). It is obvious that positions with equal perimeter along the surface of a cone exhibit a relatively bigger radius at the flat pattern of a stronger pointed cone

(left) and a relatively smaller radius at
the flat pattern of a less pointed cone.
(right).

Because a cylinder is an extreme type of a cone with the theoretically most pointed shape, where the pointed edge is located at an infinite distance, cylindrical pulleys, in contrast to double symmetric conical pulleys, show no lateral belt centring effect (Fig. 17).

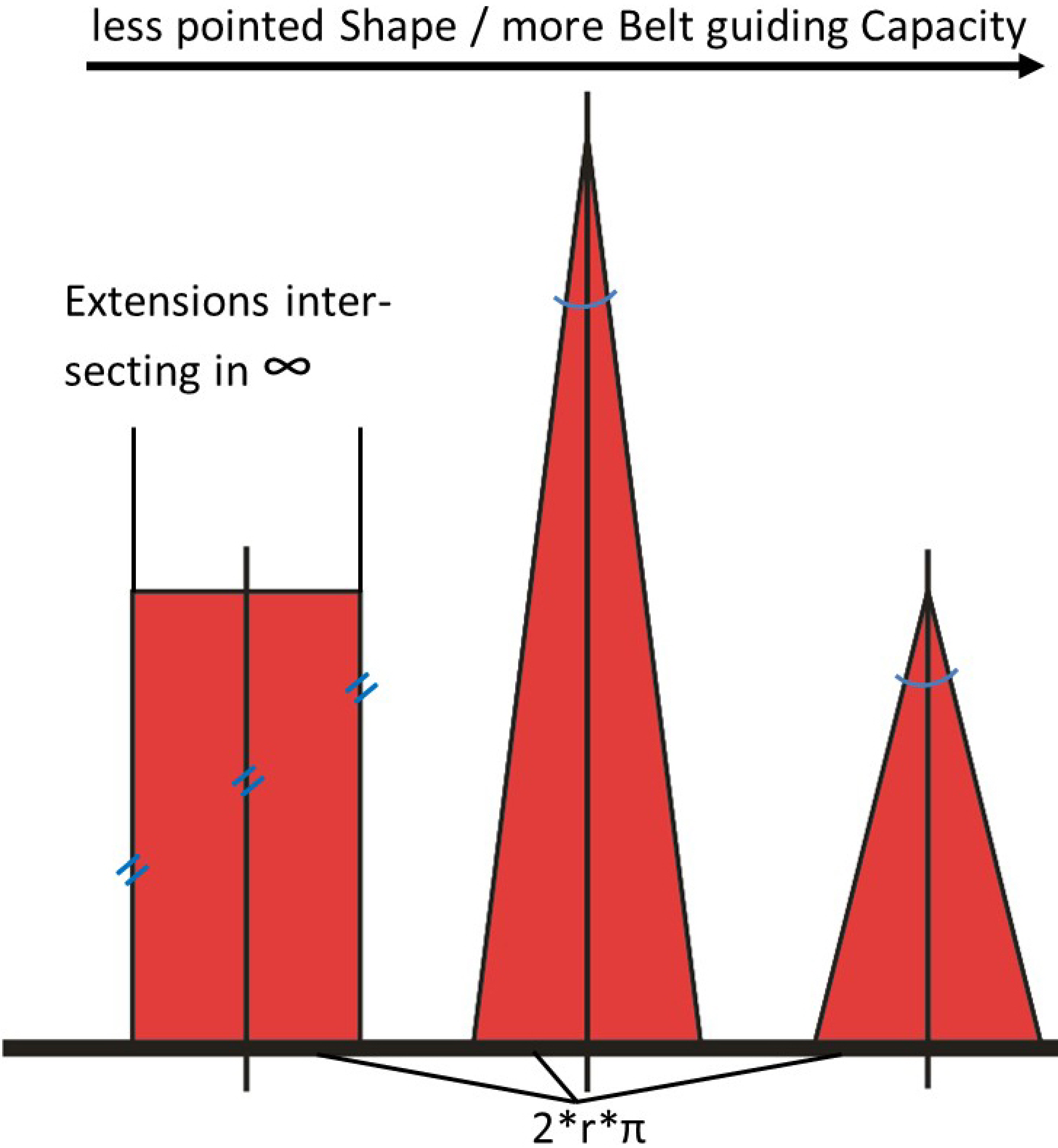

Fig. 17: side views of pulleys. A cylinder can be geometrically explained as a cone with its pointed edge at an infinite distance and with an extremely pointed shape and an extremely small opening angle.

If a belt is initially misaligned towards relatively small diameters it has to be determined if the conical pulley will be able to track the belt back towards relatively big diameters. Depending on the central angle of the flat pattern of a conical pulley and on the actual lateral position of the belt it has to be considered how much wrap angle, or revolutions respectively, is needed until the belt is directed perpendicularly to the junction line of the cone. Herby it is to be considered that the belt has to be directed towards relative bigger diameters of the cone before it leaves the conical pulley at its pointed edge.If the lateral radius of curvature of the belt and subsequently the actual angle between the belt and the junction line of the cone at the boundary line are dynamically influenced by appropriate actions, accordingly the lateral running behavior of the belt is changed and will exhibit a dynamic behavior (Fig. 18).

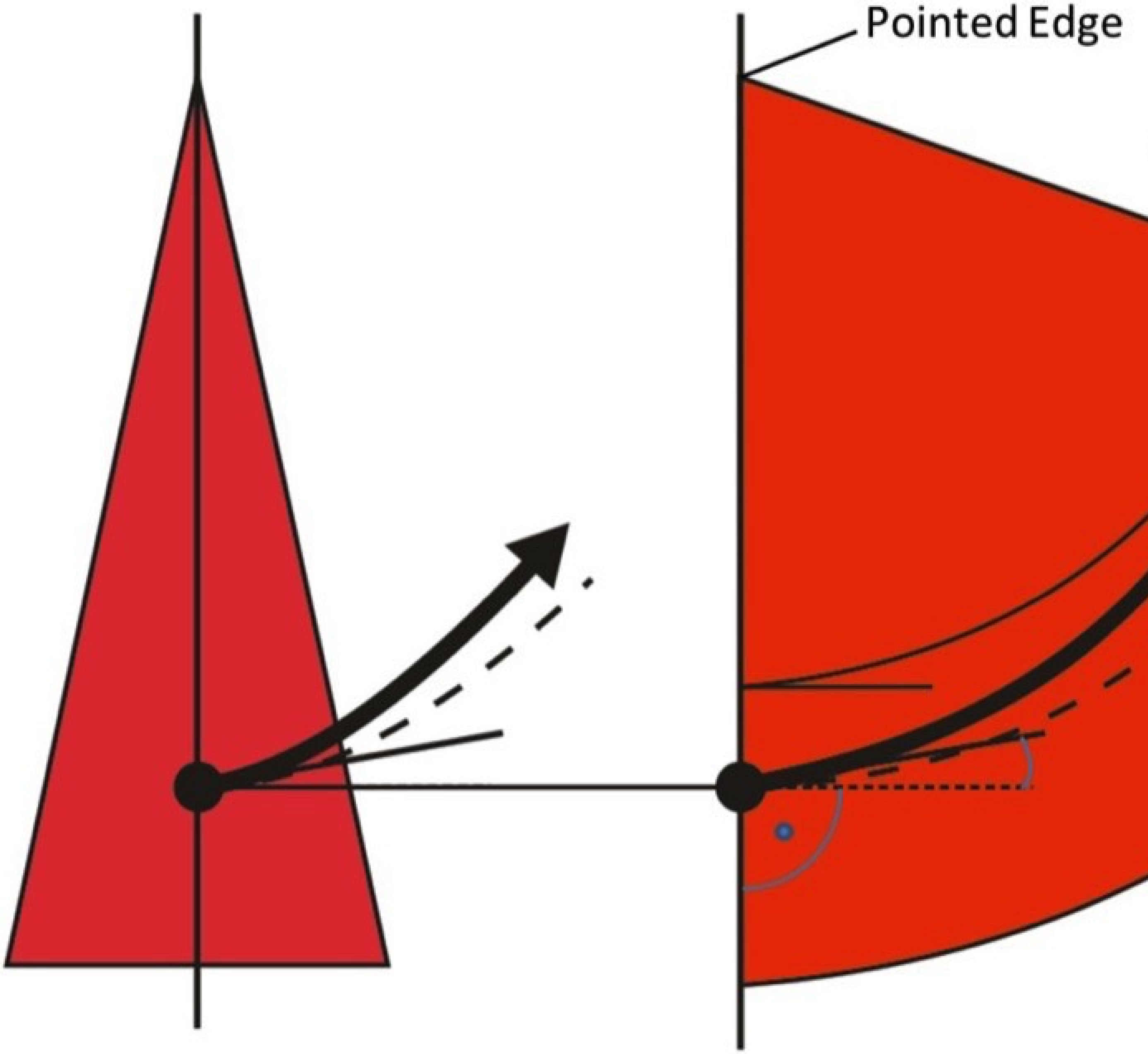

Fig. 18: Cone with its flat pattern and a bent belt. The centerline of the belt (black arrow), regarded directly at the boundary line between the belt and the cone, is arbitrarily angled to the junction line of the flat pattern and additionally bent with an unconstant radius of curvature. The constant

lateral position (dashed line) is
indicated at the circular sector of the
flat pattern of the cone.

Crowned pulleys have to show a relatively smaller diameter at both edges, compared to their central part, because their geometry is then able to compensate for the effect of both sides at the bigger, central radius of the pulley and therefore the belt will be guided to the central area of that pulley.Pulleys used for practical applications usually exhibit more complicated geometric shapes than a symmetric conical pulley, making the situation more complex. If, as opposed to a symmetric conical pulley, a pulley with a more complicated geometry were considered, the guiding effects would be working according the same principals, but the deformation geometries would be more complicated.Therefore it can be seen, that the angular direction at the boundary line between a pulley and a belt, combined with the actual radius of curvature of the laterally bent belt and the geometry of the pulley together with the actual lateral location of the boundary line between the pulley and the belt, are mainly influential in determining the behaviour of the lateral position of the belt running around that pulley. For a quantitative mathematical explanation of belt - centring effects of crowned pulleys all these conditions have to be considered.

4. Twisted Pulleys

In this description, to twist a pulley, means to turn it around the principal, longitudinal direction of the conveyor belt. Due to twisting a cylindrical pulley, two principally different effects will influence the lateral running behavior of the conveyor belt [6, 3].

4.1 Lateral Shift Effect

If a pulley is twisted around the longitudinal direction of the conveyor, the exiting strand of the belt will be shifted laterally relative to the ongoing strand of the belt according to pure geometrical conditions. The lateral deviation will always occur if a pulley is twisted and it will be generated according to the actual position of the twist axis, to the twist angle of the pulley, to the radius of that pulley and to the actual lateral position of the belt on the pulley. Belt guiding by twisting a pulley has the advantage that only minor changes in the distribution of stresses within the belt will occur, while one disadvantage could be spillage of material due to the twisted pulley.Only if the center of the twist rotation of the pulley is located along the boundary line between the ongoing belt and the pulley and if it is additionally located laterally at the center line of the belt, the lateral situation at the right side and at the left side of the ongoing belt remain symmetrical (Fig. 19).

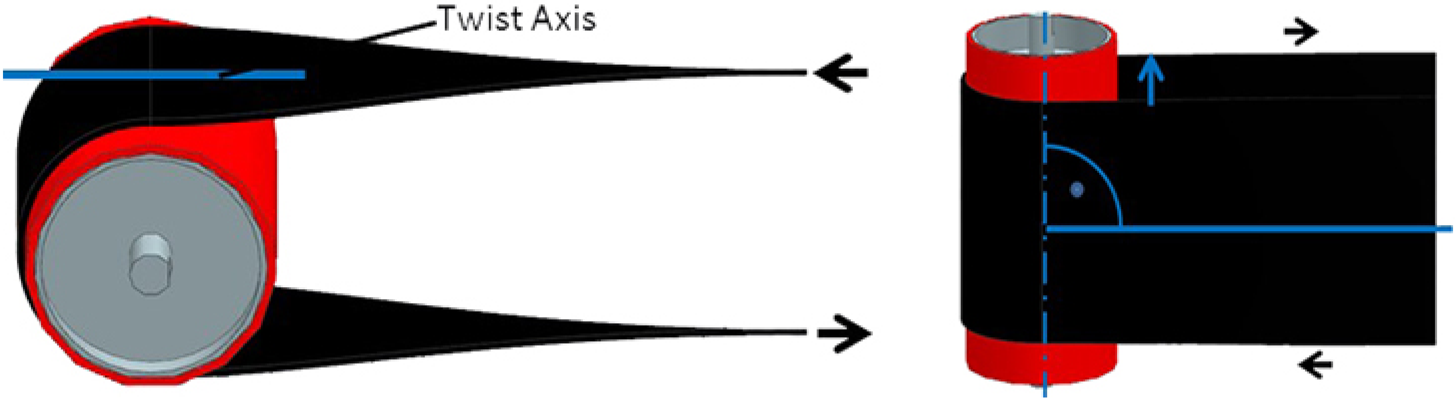

Fig. 19: Side (left) ground (centre) and back (right) views of a pulley with the corresponding belt, while the pulley is twisted around the longitudinal direction of the conveyor. The black arrows represent the running direction of the belt, the blue arrow indicates the direction of the relative belt shift, valid for the actual belt running direction.

The lateral symmetry will cause the belt to run onto the twisted pulley at comparable lateral angles on both sides whereby the effects at both sides will be compensated by each other. This case resembles the most pure kind of twisting a pulley because here the ongoing belt is almost only twisted around its longitudinal center line but the exiting belt is additionally shifted laterally. Therefore for the case where the center of the twist rotation is located directly at the boundary line between the ongoing belt and the pulley and if it is additionally located laterally at the center line of the belt, mainly the effect of the lateral shift of the exiting belt will be effective.

4.2 Effect at the ongoing Side of the Belt

The situation at the ongoing side of a belt will change according to the twist movement of a pulley, which correspondingly changes the lateral running behavior of this belt. The geometrical changes are thereby mainly influenced by the twist angle and especially by the position of the center of the twist rotation. The center of the twist rotation influences the resulting lateral position of the pulley and therefore the lateral position of the boundary line between the ongoing belt and the pulley. This again influences the lateral angle between the ongoing belt and the twisted pulley.If the center of the twist rotation of the pulley is located below or above the boundary line between the ongoing belt and the pulley, or if it is located laterally beside the center line of the belt, or if a combination of these two cases occurs, twisting will laterally shift the whole pulley including the ongoing belt according to geometrical conditions. Thereby as well a relatively big distance between the boundary line and the center of the twist rotation as a big lateral distance between the center line of the belt and the twist axis cause a relatively big lateral shift.The relative change of the lateral position will alter the angle between the ongoing belt and the pulley. This lateral shift makes the situation between the pulley and the ongoing belt somewhat comparable to the situation with tilted pulleys (see Chapter 2). Thereby this angle is always influenced by the way that the belt will laterally move towards the side from which the twisted pulley was initially deviated away. For the case that the center of the twist rotation is located below (Fig. 20) the boundary line between the ongoing belt and the pulley, the effects due to the lateral shift of the exiting belt and of the ongoing belt are added and amplified.

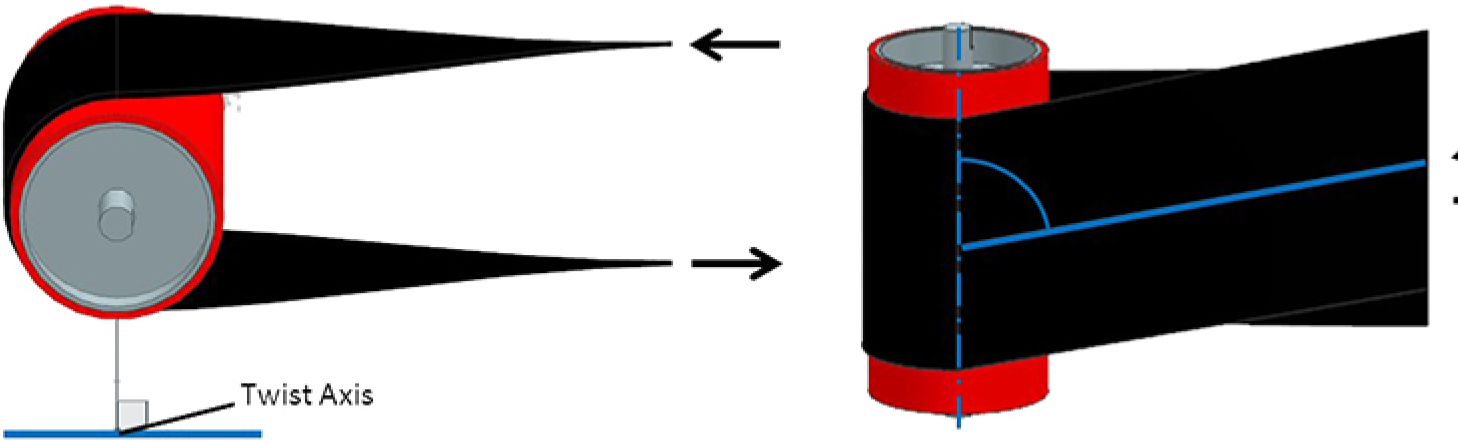

Fig. 20: Side (left) ground (centre) and back (right) views of a pulley with the corresponding belt, while the pulley is twisted around the longitudinal direction of the conveyor, with the center of the twist rotation located below the boundary line between the ongoing belt and the pulley. The black arrows indicate the running direction of the belt, the angular direction between the ongoing belt and the pulley is shown in blue color.

For the case that the center of the twist rotation is located above the boundary line between the ongoing belt and the pulley, the effects due to the lateral shift of the exiting belt and of the ongoing belt are directed opposite to each other and only the resulting difference will be effective.

Conclusion

The explanations given in this article show descriptively that the lateral behavior of a conveyor belt at a pulley is determined at the ongoing boundary line. The determining factor is the angle between the belt and the pulley, considered at their boundary line, while this angle is influenced by the lateral shape of the deflection curve of the belt. Hereby the interactions between a pulley and a belt, which define the corresponding belt tracking properties, are explained descriptively due to a proper visualization of their geometrical conditions.For this purpose, among others, the geometric properties of the flat pattern of the surface of a pulley combined with the schematic centre line of a belt are used. In particular belt tracking properties of cylindrical pulleys and of crowned, especially symmetrically conic pulleys, are discussed. Additionally the principal effect, why crowning the shape of a pulley works for belt centering purposes, is explained descriptively by illustrating the geometrical properties of more or less pointed cones.

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