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LATERAL RUNNING BEHAVIOUR OF CONVEYOR BELTS

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Abstract: Correct guiding is of major importance in the operation of belt conveyors. Faults such as incorrect geometry, uneven load distribution or belt splicing cause lateral movement of the running belt. The running behaviour of the belt is largely dependent on its deformation at the point where it meets the drums. For precise automatic control, it is necessary to know the belt position, the inclination between drum and running direction and the curvature of the belt at this point. This data is also necessary in order to check the accuracy of the mechanical models developed to simulate the running behaviour of the belt. This paper deals with the lateral running behaviour of the belt on a skewed tail pulley as well as a conical tail pulley. Belt deformations were recorded by a CCD camera as well as by conventional potentiometer distance sensors. The resultant measurements were compared with the mechanical models.
Keywords: belt conveyor, CCD, distance sensor

1 INTRODUCTION

Correct guiding is of major importance in the operation of belt conveyors. Faults such as incorrect geometry, uneven load distribution or belt splicing cause lateral movement of the running belt. Most guiding systems are based on empirical solutions, these cause additional belt stresses and frictional forces, rapid wear and tear of the belt edges will occur. Some important influences on the running behaviour of the belt are also investigated in [1] and [2] include:

- Skewed pulley;
- Conical pulley;
- Force exerted to the belt transversal to its running direction, for example by an skewed idler.

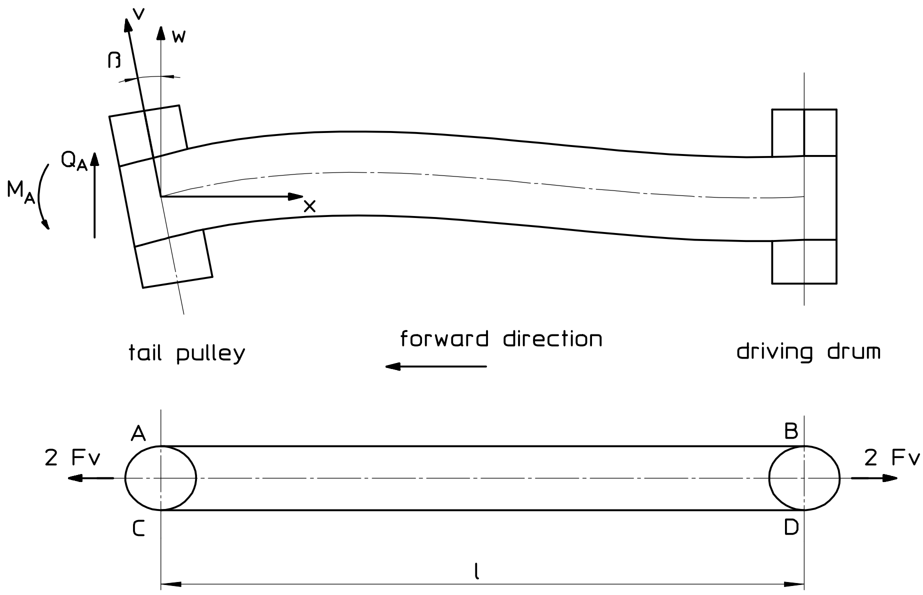

Figure 1. Belt conveyor with a skewed tail pulley, causing the belt to run at lower tensions

Figure 1 shows a belt conveyor as used in our experiments. The skewed tail pulley deforms the running belt, resulting in a lateral movement to lower belt tensions. The effects of skewing pulleys and idlers are well known, and they are sometimes used for automatic control of the lateral band position. It is also a generally known phenomenon that flat conveyor- and transmission belts which are driven by crowned drums, run to the largest diameter of these pulleys. For the true running of the belts cylindrical drums with conical shaped ends are applied. Knowledge of the running characteristics of he belt is important when designing guiding systems. The Institute for Design Engineering and Transport-, Handling-, and Conveying Systems has been studying this problem for some years. We have developed a theoretical mechanical model to simulate the lateral running behaviour of the belt, and investigate the influence of the belt and application parameters. The aim of the study is to check the accuracy of the mechanical model and compare two different methods of measuring belt deformations. This paper deals with the running behaviour of the belt on a skewed tail pulley as well as a conical tail pulley.

2 THE TEST BENCH

Theoretical investigations show that the shape of the centre line of the belt at the point where it makes contact with the drum is responsible for the lateral running behaviour. In order to verify the developed mathematical model, deformations of the belt in this area are recorded by an CCD camera as well as by conventional potentiometer distance sensors. This data makes it possible to determine the position of the belt on the drum, the angle between the drum and the running direction, as well as the curvature of the belt at the point where it meets the pulley. The results of these experiments are used to check the accuracy of the theoretical mechanical model, and this data is also the basis for the design of a fast automatic control system. The measurements were conducted in the laboratory of the Institute for Design Engineering and Transport, Handling and Conveying Systems of the University of Technology Vienna. The test bench is equipped with two electrical linear drive devices to control the position of the tail pulley. Belt feed is detected by an optical sensor fixed near the speed control driving pulley. Experiments can be carried out with automatic monitoring by a PC. Data acquisition is achieved by an additional PC equipped with an A/D acquisition board encompassing the recording of the position and shape of the belt edge, and belt feed as well as the resultant forces exerted on the bearings of the pulleys.

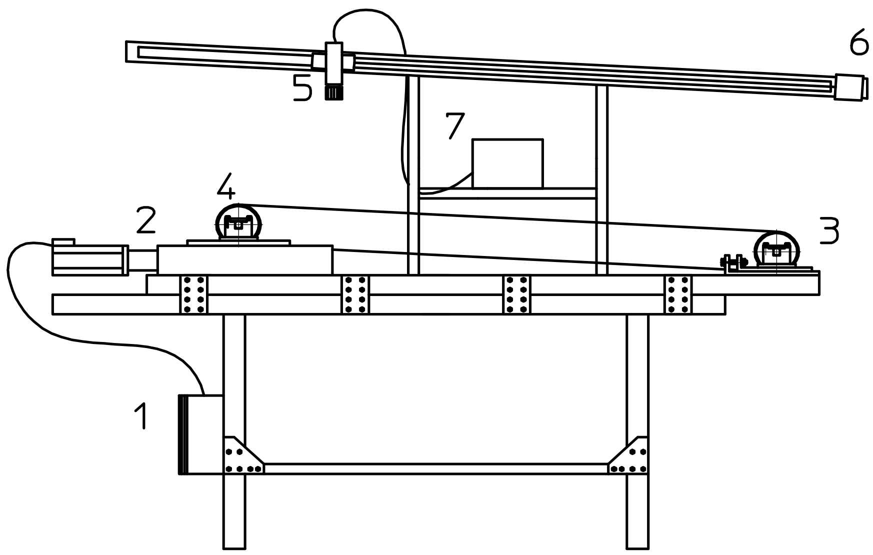

Figure 2. Test machine: 1. Control unit for linear driving device and driving pulley; 2. Electrical driving device to displace the tail pulley; 3. Driving pulley and feeding detector; 4. Tail pulley; 5. CCD camera for detecting the belt edge; 6. Driving unit of the CCD camera; 7. Evaluation unit of the CCD camera.

Figure 2 shows a schematic diagram of the test unit. The drums are each 600 mm long, and the width of the largest useable belt is about 500 mm. Six types of belts were available for the experiments, but in order to limit the extent of this paper only the results of the 125 mm width belt are presented. The nominal diameter of the drums is 163 mm, and the nominal centre distance between drums is 2000 mm.

Two types of tail pulleys are available, a cylindrical drum as well as a conical drum with a 154.4 mm diameter for the smallest diameter and ending with a 158 mm diameter. Belt speed can be varied between 0 and 1.2 m/s. Belt tension was adjusted as required.

Specifications of the belt used: Habasit SAB 8EV, k_{zul}:15 N/mm, $k_{\varepsilon 1}$: 8 N/mm, thickness: 2.1 mm

3 BENDING OF THE BELT DUE TO A SKEWED TAIL PULLEY

Figure 1 represents the model of a belt with two cylindrical drums. It is assumed that the rules of the theory of elasticity as applied to steel are also valid for conveyor belts. This means that the modulus of elasticity of the belt can be assumed as a fixed value, and every cross-sections of the belt remains flat and remains to stand perpendicular to the neutral line. Tests proved that these properties are fairly well applicable to the used belts. We considered a tensioned belt initially lying in a straight line along its track. Skewing the cylindrical tail pulley causes deformation of the belt and using the second order bending theory, the resulting bending line of the part between the drums can be described by equation (1).

$$w(x) = C1\sinh(\sqrt{g}\,ax) + C2\cosh(\sqrt{g}\,ax) + \frac{M_A - Q_A * x}{Fv} + w_A \quad (1)$$

with
$$a = \sqrt{\frac{Fv}{EJ}} \quad (2)$$

and
$$g = \frac{1}{1 + \dfrac{Fv}{G * A}} \quad (3)$$

The constants *C1*, *C2, M_A* and Q_A depend on the acute boundary conditions at Point A and Point B according to Figure 1. Experiments showed that it is not valid to consider the belt being clamped by the drums. Sliding friction occurs and therefore the boundary conditions them self depend on the skewing angle and the friction coefficient between drums and belt. In order to simplify the mathematical model, the action of the friction force is considered as two areas of a constant line load acting between drum and belt. The extensions of the areas of friction depend on the exerted bending torques and hence on the deviation of the belt given in equation (1). This problem leads to a system of twelve non-linear equations which can be numerically solved. Figure 3 compares the results of different mathematic models and the measurements carried out by the CCD-camerea as well as by potentiometer sensors.

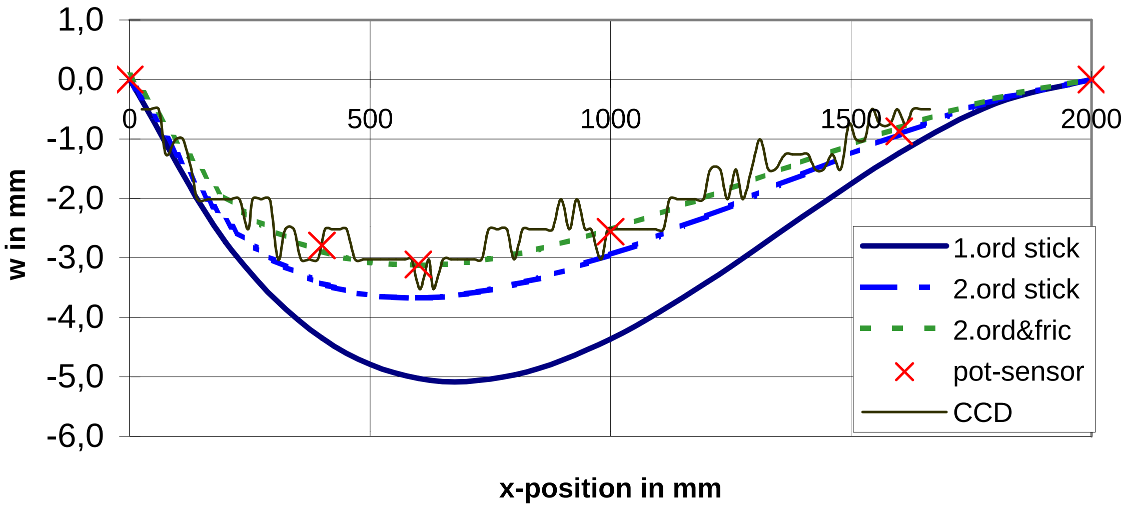

Figure 3. Bending line of a belt due to a skewed tail pulley, belt 125 mm, skewing angle: 1°, strain: 1%

The influence of the high tensile force and also the influence of the sliding phenomenon can be seen. The line *'1.ord.stick'* represents a clamped belt neglecting the action of the tensile force, line *'2.ord.stick'* represents a clamped belt considering the tensile stresses, and the line *'2.ord.slip'* represents the mathematical model considering both effects, the tensile stresses as well as the sliding effect. Close correlation can be observed between the calculation and the measurements. The recorded line graph deviation against belt position is not very smooth due to the finite resolution of the CCD camera. A 10 bit line scan camera is used to detect the edge of the belt in an area of about 240 mm, this provides a resolution of 0.234 mm per bit, sufficient to assess the measured deformations. The applied setup of the measurement device permits measurement of both deformation and lateral movement of the belt.

4 SKEWED CYLINDRICAL TAIL PULLEY

A belt guided by a drum whose axis of rotation is not perpendicular to the centre line of the conveyor will run out of true in the direction of lower belt tensions, i.e. in the direction of the acute angle between the belt's centre line and the drum. The belt will unroll itself over the drum barrel and the belt's axis performs a helical line. Figure 4 depicts the situation on the skewed pulley.

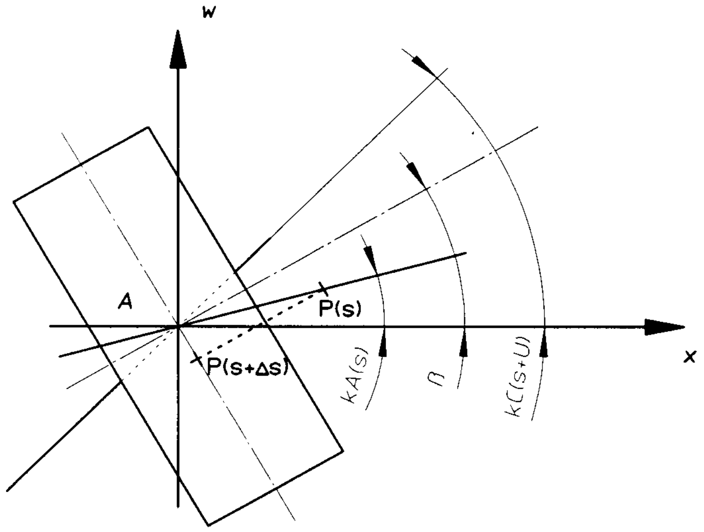

Figure 4. The belt approaches the drum at an angle $k_A(s)$

Performing a small section of feed, a new segment of the belt approaches the drum, the new condition of the belt in point A can be calculated by equation (4) and (5). Changing boundary conditions cause different bending moments and hence different friction areas between drum and belt. The resulting belt deformation is calculated as shown in the previous chapter and the lateral belt movement can be simulated step by step. After feed of half a drum circumference, the previous point A becomes leaving point C, and the condition of the belt at C considered in a fixed coordinate system are given by equation (6) and (7).

$$w_A = w_{A0} + (k_{A0} - \beta)\Delta s \quad (4)$$

$$k_A = k_{A0} + \rho_{A0}\Delta s \quad (5)$$

$$w_C(s+U) = w_A(s) \quad (6)$$

$$k_C(s+U) = 2\beta - k_A(s) \quad (7)$$

Figure 5 shows the lateral run-out of the belt using a skewed tail pulley. After a short period of oscillation the belt reaches a condition of constant lateral velocity. The belt runs down the drum, lowering the tension. A close correlation was found between the theoretical mechanical model and measurements obtained from practical tests.

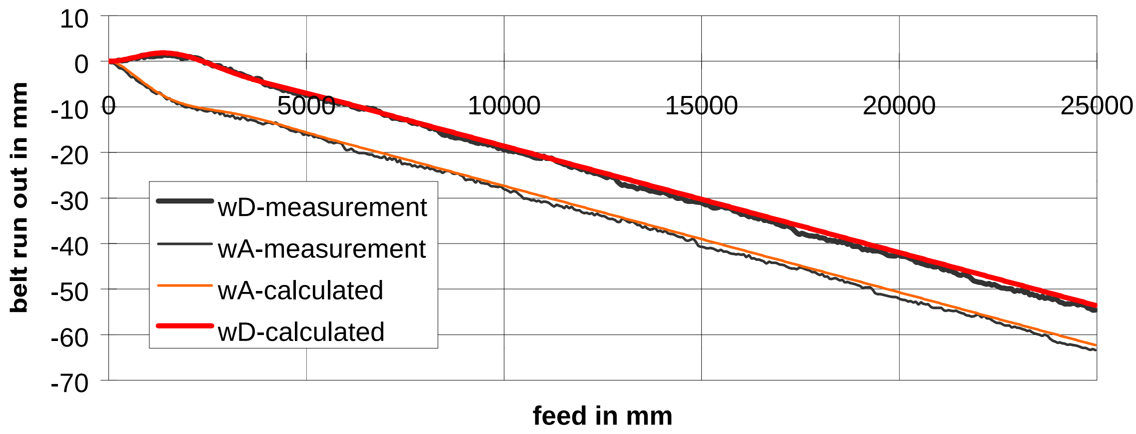

Figure 5. Belt run-out on a skewed tail pulley, belt 125 mm, skewing angle: 0.5°, strain: 0.8%

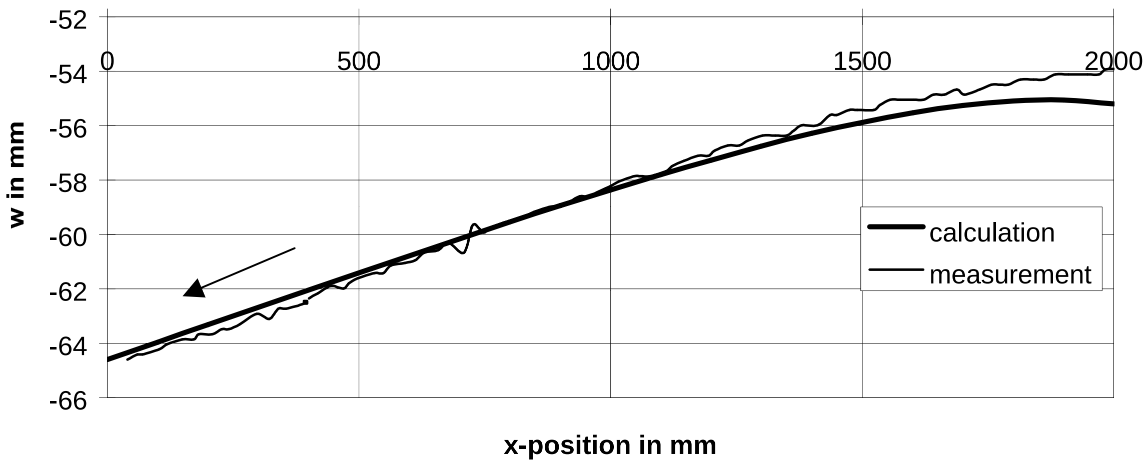

Figure 6. Deformation of the top flange after several revolutions, belt 125 mm, skewing angle 0.5°, strain: 0.8%

After several revolutions of the driving pulley the belt reaches a quasi-static condition. The lateral velocity of each point of the belt is equal hence its deformation is constant. Figure 6 depicts the shape of the belt's edge measured by the CCD line scan camera as well as the shape of the belt's centre line calculated using the developed mathematical model.

The inclination in the approaching part is responsible for the lateral velocity. Good correlation was found between measurement and calculation in this part of the belt but the calculated curvature could not be detected in the leaving part. The possible reason for this effect is that the slipping phenomenon was neglected in order to simplify the model. But as can be seen, there is no influence on lateral belt velocity.

5 CONICAL TAIL PULLEY

It is also a generally known phenomenon that flat conveyor or transmission belts which are driven by a conical drum will run out of true. Although the drum axes are parallel, the belt moves up to the larger diameter of the cone. After a short period of oscillation, the belt regains a condition of constant lateral movement. In this quasi-static state the belt runs curved to the pulley but the pitch angle between belt and drum remains constant and determines the lateral velocity. The deformation of the belt is measured and compared with the theoretical result in respect of the point where it approaches the conical drum. Figure 7 depicts the situation at the conical pulley.

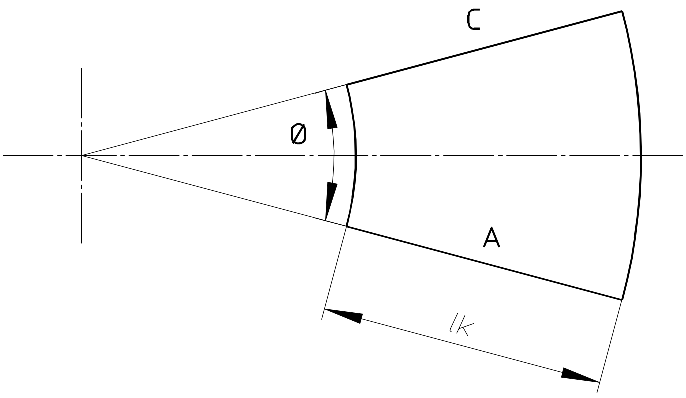

Figure 7. Drum cam of the conical pulley

The function of approaching the cone is similar to the cylinder. Comparing the drum cams we find that the conical one is curved. To consider this phenomenon in the mechanical model, equation (5) is extended as follows:

$$k_A = k_{A0} + \rho_{A0}\Delta s + \rho k \Delta s \quad (8)$$

with

$$\rho k = \frac{\phi}{Dm \cdot \pi} \quad (9)$$

As mentioned above, consideration was given to a conical tail pulley where the axis of rotation is perpendicular to the centre line of the conveyor. Figure 8 shows the lateral run-out of the belt using a conical tail pulley. The belt moves to the largest diameter of the drum.

It is difficult to realise the exact starting conditions occuring in the experiments using the mathematical model. To achieve better results at the beginning of the lateral movement, the starting conditions must be calculated using the model presented in chapter 3, applied to the conical drum.

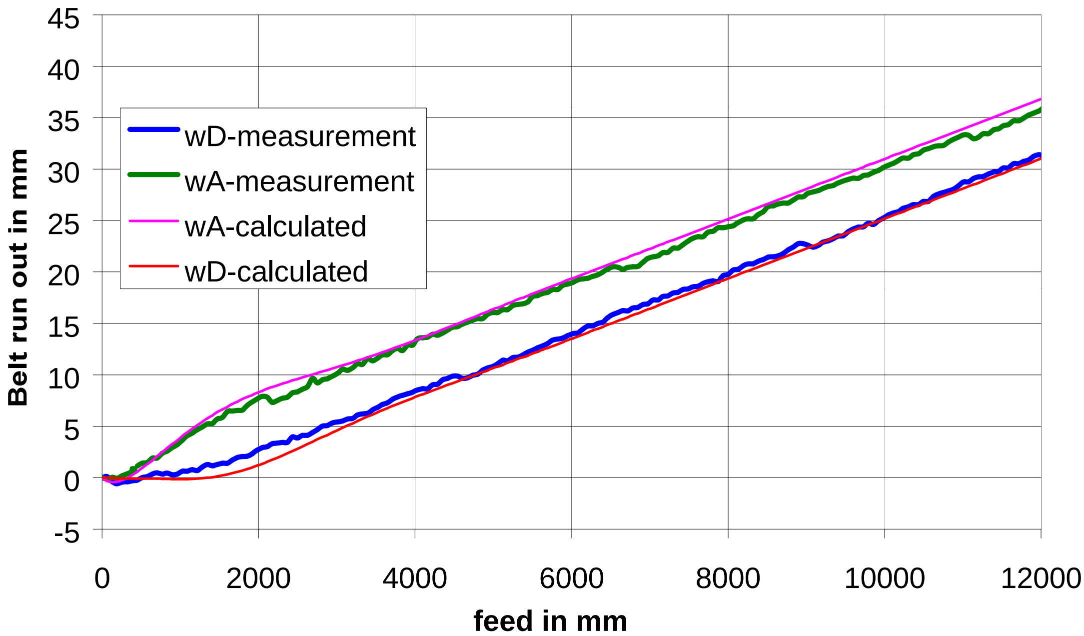

Figure 8. Belt run-out on a conical tail pulley, conical drum F =0.34°, belt 125 mm, strain: 0.8%

Figure 9 depicts the shape of the belt's edge measured by the CCD line scan camera compared with the calculated shape of the belt's centre line. A close correlation was found between the theoretical mechanical model and measurements obtained from practical tests.

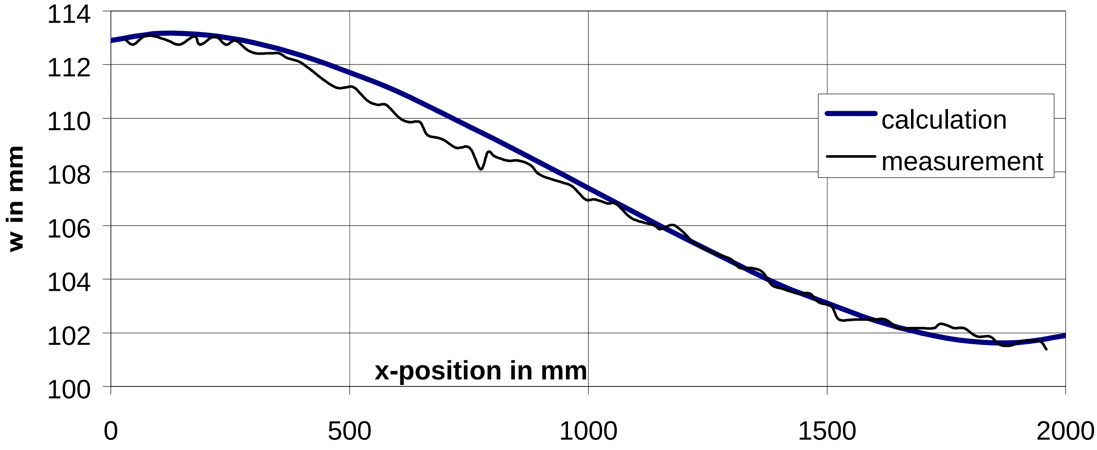

Figure 9. Deformation of the top flange after several revolutions, conical drum F =0.34°, belt 125 mm, strain: 0.8%

6 NOMENCLATURE

C1,C2	constant of integration
M_A	bending moment in A
Q_A	lateral force in A
Fv	tensile force
EJ	flexural rigidity
G	shear modulus
A	cross sectional area of the belt
s	belt feed
w_A	position of the centre line of the belt approaching the tail pulley (point A)
k_A	pitch angle between belt and tail pulley in A
r_A	curvature of the belt in A
w_C	position of the centre line of the belt leaving the tail pulley (point C)
k_C	pitch angle between belt and tail pulley in C
b	skewing angle of the tail pulley
U	half circumference of the drum
D	mean diameter of the conical drum
f	beam angle of the cone cam

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