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INFLUENCE OF THE HOISTING DRUM WINDING SYSTEM ON THE END PLATE LOADS

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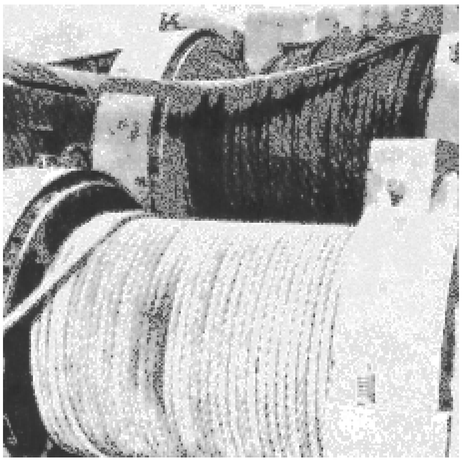
1. Introduction

The rope drums originally used in the material transport and hoisting technology had smooth drum cylinders. This brought with it the restrictions (according to §21 of the Unfallverhütungsvorschriften [Ernst 1950]) that the rope could only be reeled in a single layer because the rope guidance was poor and the risk of cutting upper layers as well as build-up of rope at one point was great (Figure 1). A multilayer wound smooth drum was therefore only used for small demands on the tensile load (e.g. magazine drum behind a driving pulley). The mantles were then later equipped with screw-shaped grooves (Figure 1), improving the rope guidance in only the first layer. A multilayer winding of this system could however not be realized under high tensile loads. In addition, the long crossing range of the individual windings leads to extensive rope wear and therewith to a shorter durability of the rope.



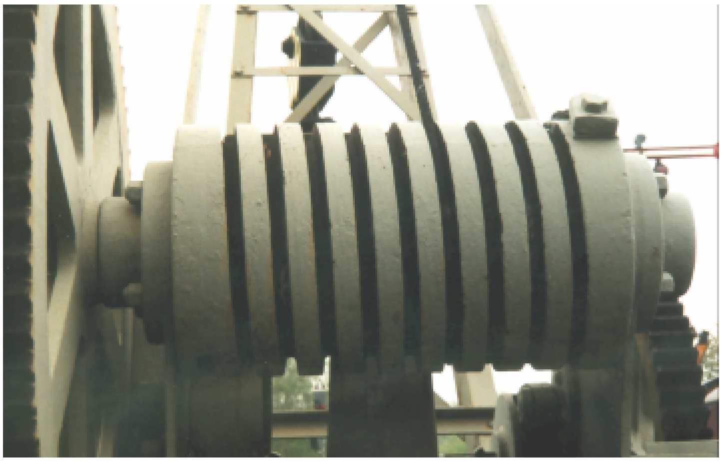


Figure 1. left: Comparison of the winding patterns, [LeBus 1969]; smooth drum cylinder with wound rope and orderly rope on a drum with winding system according to LeBus; right: Example of a single-layered drum cylinder with screw-shaped winding grooves (mobile crane from the 1920s)

2. Hoisting drum winding system according to LeBus

In the beginning of the 1960‘s, the company LeBus International Engineers introduced a new winding system that has found wide application in the field of lifting and salvaging winding drums. This winding system, generally referred to as Lebus-winding, is characterized by four peripheral regions, two parallel and two inclined sections, in which the rope is diverted by a half of a winding spacing

(Figure 2). The angular expansion of the parallel and inclined sections varies from design to design and is dependent upon the type of application, the rope diameter, the drum dimensions and the rope flexural stiffness. The parallel sections are normally larger than the inclined sections, they take up ca. 50 to 80% of the drum surface. In order to support the rope guidance in the region of the rope uptake and during the rise to the next layer, balancing and inclined elements are often installed in the first layer.

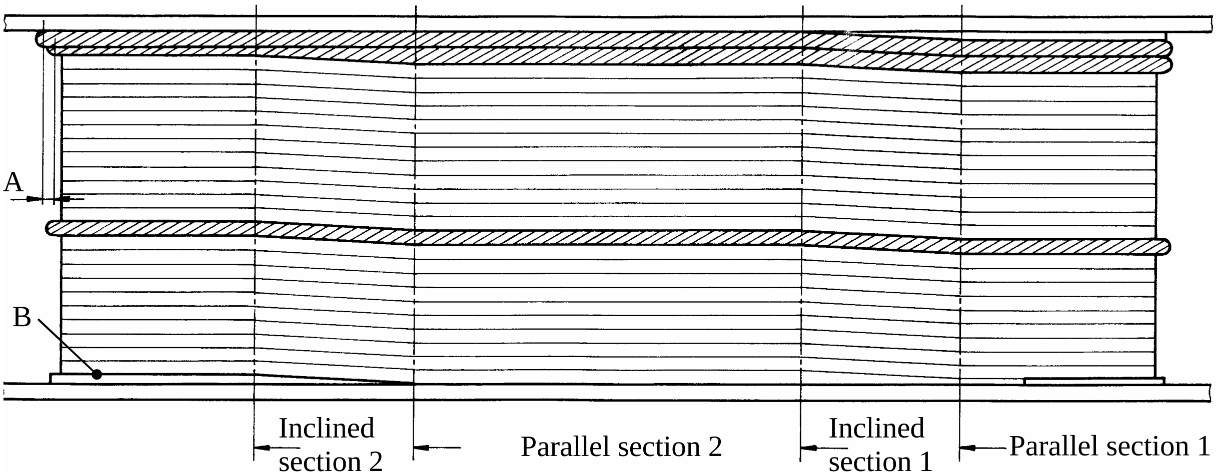


Figure 2. Unwound rope drum with Lebus-winding; A) rise to the next layer; B) balancing and inclined element

With the Lebus-winding, the rope experiences a defined guidance even in the upper layers because the lower layers take up the function of the grooved drum. This results in a orderly rope arrangement that makes a high number of layers and thereby a compact rope drum design possible. The relatively small angular expansion causes a shortening of the crossing range in the winding of two neighboring layers by which the rope wear and the flattening of the rope cross-section is limited locally. Another aspect which is to be considered more closely is the changed contact ratio between the rope and end plates in comparison with the smooth and screw-shaped grooved rope drums.

3. Winding process

For a rope drum with Lebus-winding, the pitch process can principally be divided into two categories: the rise (reshifting) of the winding in the axial direction and the rise of the last winding to the next layer. The ascension to the next layer takes place in several phases. The resulting contact conditions are important for the stress at the end plate and thereby also for their sizing. The raising of the rope can be described as follows (Figure 3):

- When the last winding "**a**" reaches the position **i+1** in the parallel section 2, then it runs along the end plate without exerting any force on it.
- In the subsequent rising section 2, the end plate prevents an axial reshifting of the rope so that it rises to the next position **i+2** on the winding (or on the rising wedge) beneath it. In this phase, a pressure is exerted on the end plate, whose working line can be described using a spiral function [Mupende 2001].
- In the following parallel section 1, the rope lies in the gap between the last winding of the lower position **i+1** and the end plate. This wedging effect continues to exert pressure upon the end plate, the working line now corresponds to an arc of a circle.
- In the next rising section 1, the rope loses contact to the end plate because it moves in the axial direction toward the opposite end plate.

When viewed comprehensively, the contact region between end plate and rope spans a maximum of 180° (one rising section and one parallel section, Figure 4). The contact zones of two neighboring layers lie 180° displaced from one another for the case of a rope drum with an integer number of windings.

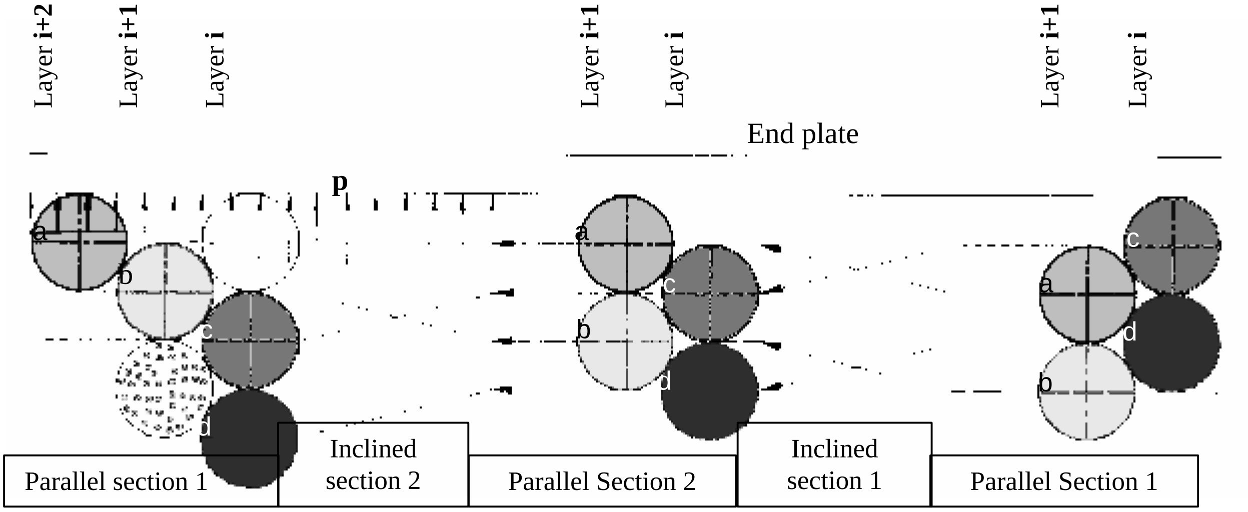


Figure 3. Representation of the winding process

The bound contact zones lead to a asymmetric stress of the end plates which was investigated at the Institut für Maschinenwesen at the TU Clausthal with the help of finite element simulations and experimental stress analysis.

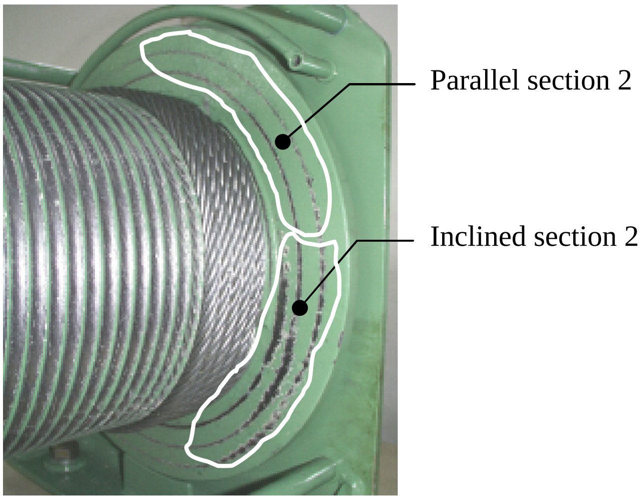


Figure 4. Contact tracks on an end plate including a rough separation of the important pressure ranges

4. Drum-winch test rig

Figure 5 shows a complete view of a testing rig with a length of 16 m. The drive pulley winch HS 200 from Rotzler is the central structural element which can achieve tensile forces of up to 300 kN and rope speeds of up to 40 m/min. In addition, the drive pulley winch offers the possibility to use ropes with diameters between 12 mm and 29 mm producing a wide spectrum of test trails. The nearly no-load rope coming out of the drive pulley winch is wound onto the magazine drum which, dependent upon the rope diameter used, can take up between ca. 400 m and ca. 600 m of rope. This high storage capacity guarantees the execution of test series in which the test winch can be wound in multilayers within a wide range.
The maximum dimensions allowed for the test piece are a wound diameter of a maximum of 800 mm

and a drum length of up to 1000 mm (corresponds to a maximum deflection angle of 1.8° in a no-load state). The investigation of larger test pieces or smooth drums with rope winding devices is also possible in individual cases when the corresponding alterations are assumed.
The execution of the experiment takes place in the automatic testing facility. It is thereby possible to vary the rope tensile force and speed in the layers so that the stress distribution of a multilayer wound drum can be analyzed under different load situations (e.g. constant tensile load in all layers or winding with low rope tensile force in the lower and with high tensile force in the upper layer). The dynamic operating behavior of rope drums and the influence of rope wear on the winding behavior can be examined through presetting the load collectives.

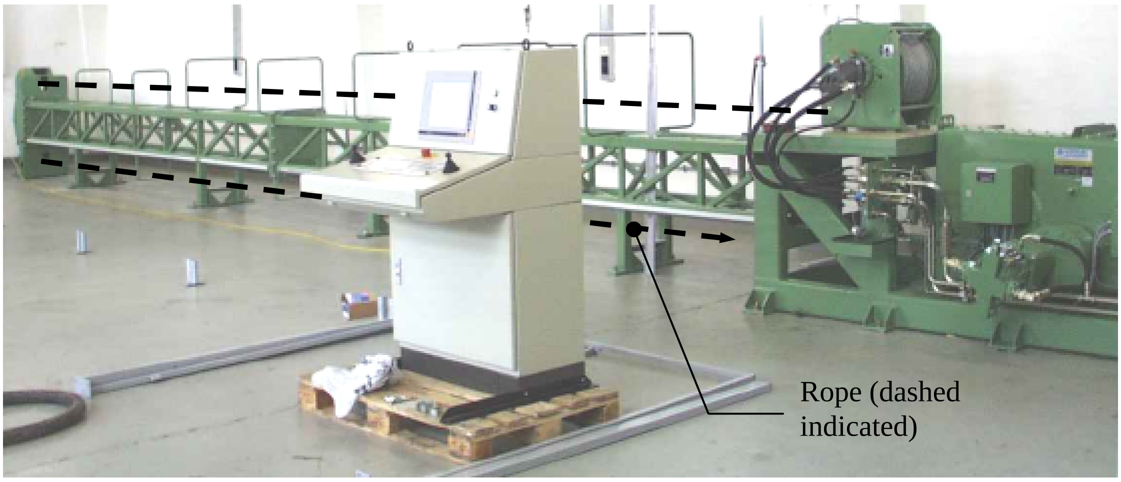


Figure 5. Universal rope drum testing rig at the start of operation

5. Measurement and simulation of the end plate stress

The detection of the end plate stress is carried out with the help of telemetric DMS multi-position measuring technology. The distribution of the measuring positions over the periphery and radius of an end plate is shown in Figure 6. The DMS grid used makes it possible to measure the expansion in the radial and tangential direction, in which the stress and deformation state of the end plate can be determined exactly.

Figure 6. DMS measuring positions along the periphery and radius of the end plate

The stress distribution (radial, tangential and equal stress) over the periphery of the end plate is shown in Figure 7 for an experiment with constant tensile force from the first to the last position. The rope, at the viewed end plate, moves upward in the 2nd rising section so that high stress can occur in this angular sector (compare Figure 7). Corresponding to the previous configuration, the rope remains in contact with the end plate in the following parallel section 1 causing the pressure load to remain constant (with decreasing tendency). The level of stress confirms the asymmetric loading of the end plate as illustrated with the winding process for a rope drum with Lebus-winding.

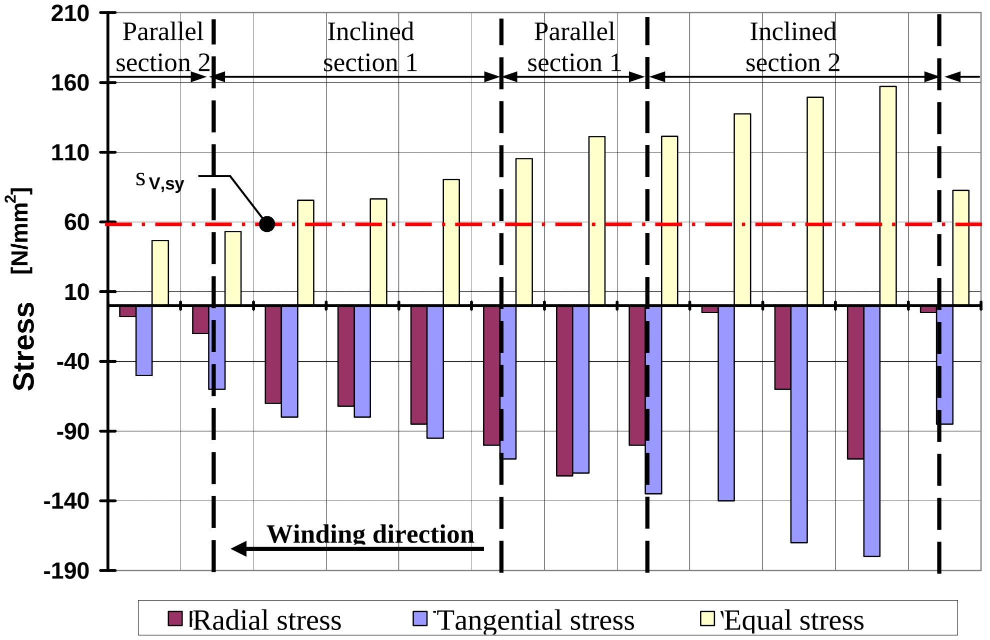


Figure 7. Stress distribution over the periphery of the end plate measured at the 5th layer ($\sigma_{V,sym}$ is the expected effective stress for a symmetrically loaded end plate)

Previously used calculation methods [Dietz 1971, Kraitschy 1973, Waters 1920, Henschel 1999] assume that the axial force on the end plate resulting from the deformation of the rope package act as linear load or pressure over the entire periphery. A symmetrical loading of the end plate is simultaneously assumed. This corresponds well with the stress behavior of smooth and screw-shaped wound rope drums in which the rope is in contact with the end plate over almost the entire periphery.
As the experimental investigations have shown, the pressure on the end plate of a rope drum with Lebus-winding is only generated within a maximum angular range of 180°. The generated stress could therefore be locally up to three time higher than previously assumed.
The asymmetrical deformation of the end plate was also determined with the help of finite element simulation. The introduction of the axial force took place on the working line of the contact zone between the rope and end plate, i.e. on an arc segment (spiral arc segment in the rising section and circular arc segment in the parallel section), in the FE model. Figure 8 shows the asymmetrical deformation of a thus loaded end plate which is distinguished by the local „folding-out“ of the highly loaded rising section (compare Figure 7). Characteristic for this type of locally limited bending deformation is the high tangential tensile stress at the outside of the end plate.

6. Conclusion

Conventional calculation methods still used today for the determination of the end plate stress are based upon the assumption of a symmetrical axial load evenly distributed along the periphery of the end plate which results from the line contact of the rope package position.
This procedure does not adequately describe the end plate stress of a rope drum with Lebus-winding. Due to the winding process, an asymmetric pressure distribution arises over the contact zone of the individual layers for this winding system which is limited to a maximum of 180° (one rising and one parallel section). Deformation and stress behavior results for multilayered rope drums with a geometrical ratio of ca. $h_B/d_B < 0.025$ and ca. $d_B/d_G > 1.8$ (end plate thickness h_B, end plate diameter

d_B, mantel base diameter d_G) which is clearly distinguished from that of a symmetrically loaded end plate.
A designer should take this behavior into account when developing multilayered light-weight rope drums in order to obtain a safe construction through realistic load assumptions.

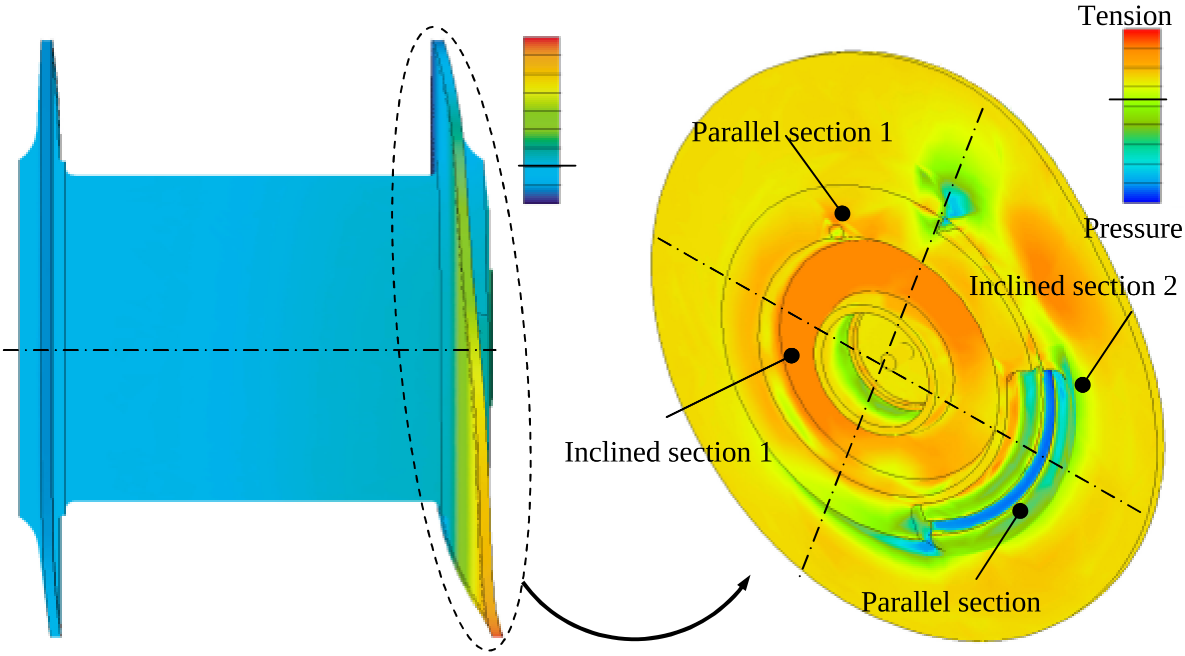


Figure 8. Asymmetrical deformation and loading of the end plate of a rope drum with Lebus-winding; FE-simulation (rope tensile force F_S = 100 kN, drum cylinder base diameter d_G = 467 mm, end plate diameter d_B = 855 mm)

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