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ISSUE OF MULTIPLE-LAYER WINDING OF ROPES ON DRUMS OF MINE-SHAFT HOISTINGS

5.1 INTRODUCTION

Multi-layer winding of ropes on cylindrical drums of hoisting machines, which are used in the shaft hoists, presently is widely used in many countries around the world (Republic of South Africa, Canada, England, Russia, Ukraine, Germany, etc.) in stationary deep hoisting devices and in winders for shaft sinking and in auxiliary emergency-rescue shafts. In Poland, the Mining Mechanization Center KOMAG in Gliwice, and Shaft Sinking Company in Bytom, already in the 70's of last century, have concentrated on issue of the multi-layer winding of ropes on drums of the mining winders [1, 5, 9, 13, 14, 15]. Currently in Poland, after decades of interruption, again there began to new shaft sinking or to shafts sinking to a depth of 1200 m of shafts, existing in coal mining. Therefore, there have appeared some problems connected with kinematics of winding and ropes' wear during their multi-layer winding.

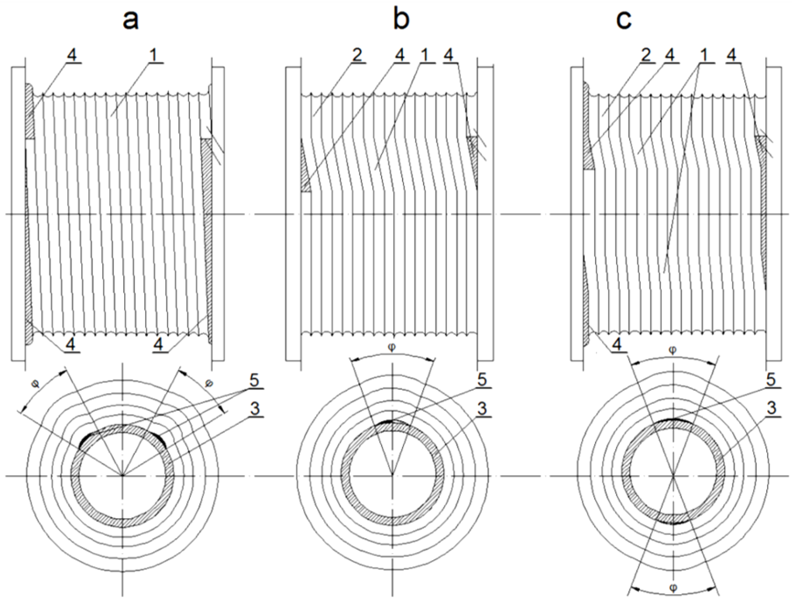

Fig. 5.1 Types of grooving the lining of cylindrical drums [14]:
a – helical grooves, b – parallel grooves with single skew transition,
c – LeBus method, parallel grooves with double skew transitions;
1 – skew grooves, 2 – parallel grooves, 3 – drum shell 4 – leading or filling wedges,
5 – crossing zones of rope transition from one layer to subsequent layer,
φ - wrapping angle of the crossing zones

In the country, a multi-layer winding of ropes was used and is still using, mainly in the winders for shaft sinking and in auxiliary, emergency, rescue and inspection shafts. In practice, multi-layer winding of ropes is applied on smooth-faced drums (abandoned in mine-shaft hoists) or in drums with the lining in which grooves are made. There is also applied direct grooving of drum shells. There can be distinguished three basic types of drums grooving and winding of ropes, fig. 5.1: helical, parallel with the single skew transition, and parallel LeBus method with double skew transitions. In the LeBus method one can distinguish LeBus synchronous and LeBus asynchronous grooving.

Helical grooving consists of the continuous spiral, which assure continuous winding at the one layer of rope, fig. 5.1a. Formerly, this type of grooving was also applied to multi-layer winding. However, due to a number of adverse effects, such as: wedging of the rope at the rims of a drum, disordered winding, seizure of rope, causing dangerous dynamic forces within the rope and its destruction, presently it is used exceptionally and only there, where parallel winding cannot not be applied *e.g.* in machines with grooves incised in the drum shell. Therefore, helical grooving is used only for one-layer or two-layer winding, however practically it is used in the winding of few layers.

Parallel grooving consists of grooves made parallel to the rims with one zone of skew grooves (fig. 5.1b), where the rope displaces by one pitch of winding corresponding to $(d+\varepsilon)$, where d – diameter of the rope, ε – slit between the coils of rope. In order to improve the rope transitions to next layer, there are placed directing-uplifting wedges in that zone.

The necessary condition for satisfactory operation of machine with multi-layer winding of rope on a drum is regular smooth compact and ordered winding of rope, both in the first, as in the subsequent layers. If the winding is irregular, there is a possibility of breakdown of rope through the already wound layer and placement on the lower improper layer, as well as the possibility of wedging of the rope at the rim of the drum, what causes an occurrence of strong jerks in the rope, transmitting on the mining vessel and causing its vibrations.

As a result of wedging the rope and vibrations caused by transition of rope from layer to layer and from coil to coil, the durability of the rope decreases, as the result of wear and cracking of wires. It should be noted, that the compact and ordered rope winding in the first layer of lining grooves influences on proper winding of the next layers, and simultaneously for the safe exploitation of the shaft hoists. The problem of multi-layer winding of ropes on drums of winders includes three issues:

- strength of the drums during multi-layer winding,
- kinematics (behavior) of rope during winding,
- durability and wearing of the hoisting rope, related to the selection of the rope lay.

In this paper, based on literature, methods of ropes winding, particularly LeBus method, are presented.

5.2 ROPE WINDING IN THE HELICAL GROOVES

One methods of multi-layer winding of rope is its winding on the drums, which are equipped with lining of grooves incised according to helical (screw) line.

The first layer of rope on the surface of cylindrical drum with incises grooves, according to helical line winds fluently and regularly. This type of winding lasts until the penultimate coil inclusive, until the last line of coil will not encounter to the gap having wedge's shape created by rims' wall of drum, and the penultimate coil, fig. 5.2. In this, so-called critical place of drum rope gradually picks up on the second layer of winding. Rope, to get in the state of equilibrium, abandons the critical place of a drum and places between the coils of first layer, *i.e.* between the penultimate and adjacent, remaining there until it comes up again to a critical place of the drum [3, 13].

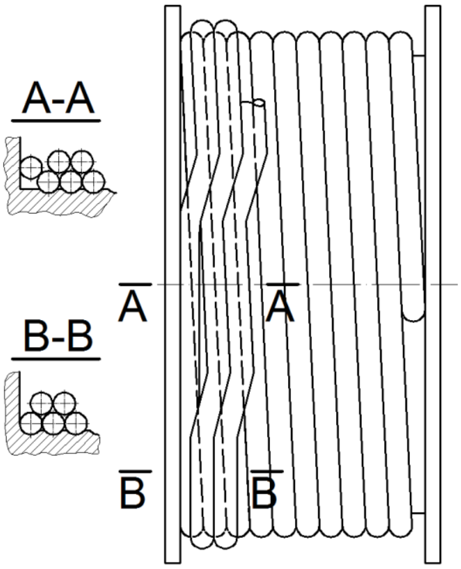

Fig. 5.2 Two-layer winding of rope on cylindrical drum with lining with helical grooves [13]

Then rope again rises from the groove formed by two adjacent coils and performs the second pitch displacement along the drum's generatrix. Such continual, pitch displacement of rope on the second layer of winding is done twice during in each rotation of the drum, fig. 5.3 [7].

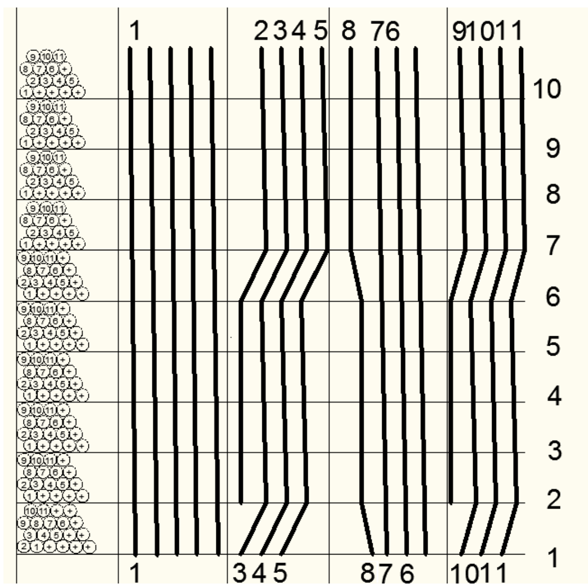

Fig. 5.3 Development of surface of the winding of drum lining with spiral grooves [4]

On the spiral grooves in the range of multi-layer winding, the coils of odd layers are laid according to the helical line, and in the even layers rope does the double pitch of displacement from coil to coil, during each rotation of a drum. In critical places next to the rims of drum wedging of the rope and disordered winding of rope occurs, contributing to cause dangerous dynamic forces in the rope. It has very negative influence on a durability of rope and may also cause damage of drum rims. Due to safety reasons, rope transition from layer to the next layer, must occur with limited or reduced winding speed.

Rope in the first layer is laid in a groove with fixed inclination angle γ related to the plane perpendicular to the axis of the drum. This angle determines the dependences, fig. 5.4 [10, 11]:

$$\tan\gamma = \frac{d+t}{2\pi R} \tag{5.1}$$

where:
t – slit between coils of rope winding,
R – radius of winding rope (drum radius)
d – diameter of rope

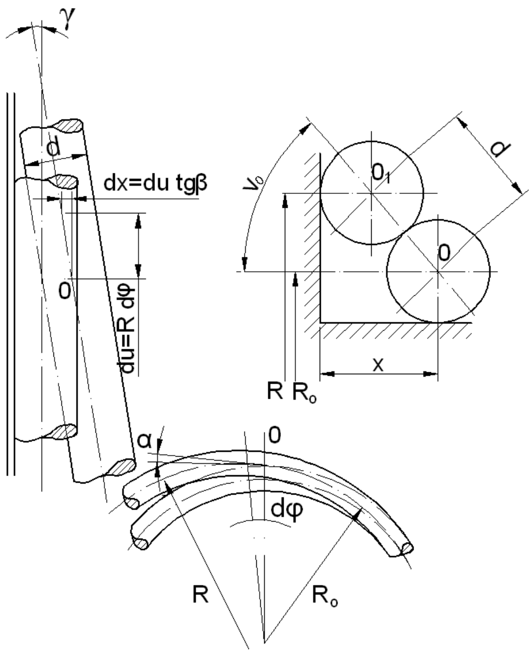

Fig. 5.4 Two-layer winding of rope on a cylindrical drum with helical grooves [4]

Assuming that the cross-section of the rope has a circular shape and do not deform, a change in winding radius during the transition from the first layer to the second, is defined by the dependences (fig. 5.4):

$$R_i = R + d \cdot V \tag{5.2}$$

where:
V – angle determining the position of the cross-section of rope coil at any critical point of the drum.

This angle in the literature is determined as coordinating angle and connected with adequate angle of drum's rotation φ. To calculate the parameters φ and R_1 the dependence according to [11] can be used:

$$\varphi = 2\pi \frac{d}{d+\varepsilon}(1-\cos w)$$

and:

$$R_i = R + d \cdot \sqrt{1-\left(1-\frac{d+t}{d}\cdot\frac{\varphi}{2\pi}\right)^2} \quad (5.3)$$

This way of rope arranging in a critical position of drum can occur only in a case when the fleet angle equals zero. Then rope is in the state of equilibrium, if the angle $V = \pi/2$, or if the rope winds itself, or is laid in groove formed by two adjacent rope coils of the first layer. In reality, in the mine-shaft hoists with drum machines, such position of the rope never occurs, because during the winding of rope fleet angles are inevitable. Therefore, the rope to be in the state of equilibrium leaves the critical place of the drum earlier than its boundary (interval) passing to the second winding layer. This pitch rope displacement along a generatrix of drum is called first transition of rope, cross-section I-I, in fig. 5.5. During the further winding of rope, if deviation angles are not excessive (in opposite case a break of coil of winding rope occurs), rope is laid in the groove created by two adjacent coils of the first layer (penultimate and the on placed close to it), until the rope will not pass the critical place of drum again from beginning. It is there again pulled out from the groove formed by two adjacent coils of winding and performs a second pitch displacement called second transition (φ_p – angle of transition) in the second layer of rope, position II-II, fig. 5.5. It results that, during each rotation of a drum, rope in the second layer performs two pitch displacements [11].

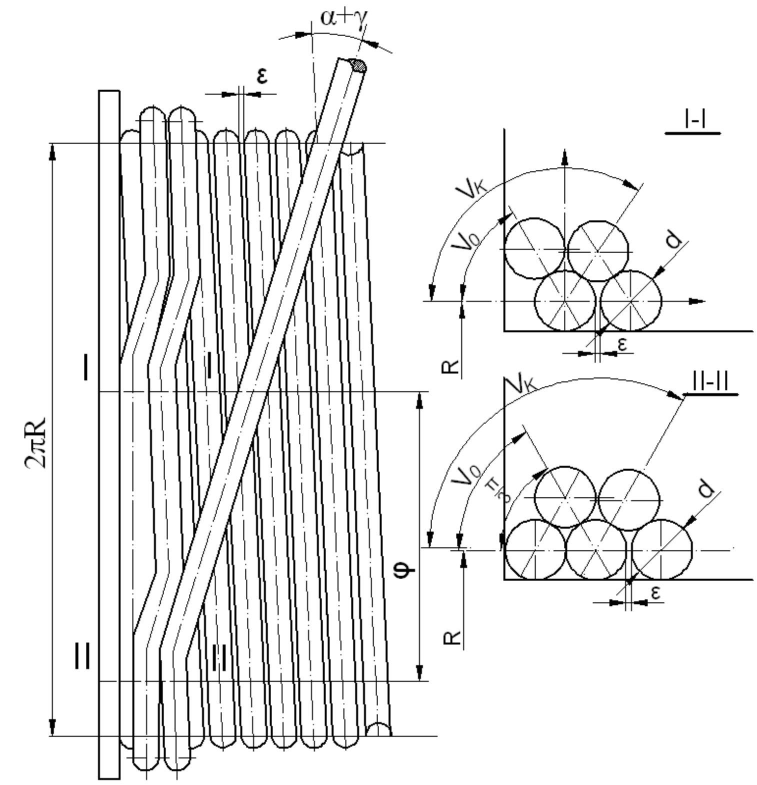

Fig. 5.5 Diagram of the rope transition from coil to coil during multi-layer winding on cylindrical drum with helical grooves [7],
I-I the first transition (the first pitch), II-II – second rope transition (the second pitch)

Behavior of rope during the transition in the second layer of winding (and in the subsequent layers) is characteristic for multi-layer winding, particularly the two-layer winding.

5.3 WINDING OF THE ROPE IN PARALLEL GROOVES

Properly multi-layer winding is possible, only with a parallel arrangement of the rope on the drum rims in incised parallel grooves in the lining or shell drum, or after the appropriate formation of the first layer of coils on a smooth drum shell. Fundamental condition for the correctly multi-layer winding is adherence of terminal coils of rope to rims of drum, that there not exists a possibility of side movement in layers. Irregular layering is caused by absence of proper side support of rope, which is caused by the incorrect winding width of drum.

Under these conditions, rope has the possibility to perform side movements, wedging and goes through the lower layer. The incision of parallel grooves in the lining or in the shell of drum with appropriate width gives the possibility to avoid the rope wedging at the rim of the drum and also to achieve the proper arrangement of the rope in the winding process at the rim and in the other coils [13].

In parallel grooved drums, rope performs one pitch in the transition from coil to coil during each rotation of the drum, both in the first, and in the last layer. To obtain the more smooth arrangement of the rope in the subsequent layers in the parallel grooves, purposeful is to make in lining or in the shell of drum, the skew grooves in places of transition from one coil to next, in which the rope moves along the drum of one diameter of the rope.

Cross-section of wound layers and developed traces of ropes are shown in fig. 5.6. Analysis of the rope transition from the first layer to the second shows that the rope moves up and inside, along the generatrix of the drum, by a half diameter of the rope. The nearest subsequent coil moves also toward the drum interior, but by the full diameter of rope.

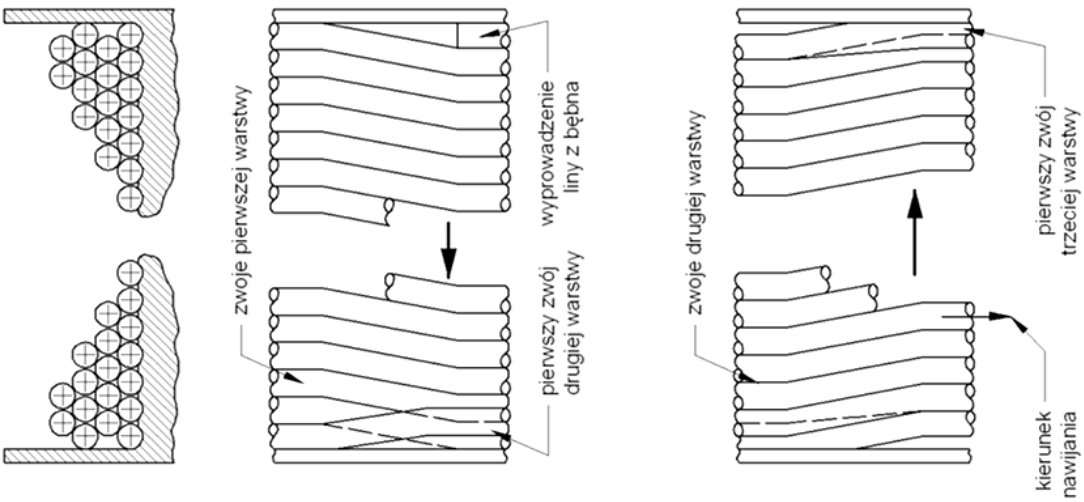

Fig. 5.6 Multi-layer winding of rope on cylindrical drum with lining with parallel [7]

The first movement of the first coil of the second layer is departing from the rims of the drum, leaving the free space equal to a half diameter of the rope.

During the winding of the second coil of the second layer, the rope goes partially through the cross shifting of the first coil, and then through the two coils in the lower layer. At the end of the second layer, during the transition to the third layer, rope moves up and toward the rim of drum, by a half of diameter of rope to the position at the rim, above the gap equal to a half of diameter of rope at the end of second layer. The next coil of third layer moves toward the interior of a drum by a full diameter of rope. Proper shiftings of rope by a half of diameter at the rims of drum are in the same direction, whereas shiftings by a full diameter of rope occur in opposite direction. In further layers winding of rope will go in the same manner, *i.e.* in the odd layers as in the first one, and in the even layers as in the second one.

The cross-section which is presented in fig. 5.6 shows, that the even number of layers contain one coil less than the odd layers. It is caused by a gap equal to a half of diameter of rope between the terminal coils of the even layer and rims of drum [13].

In each layer the same number of coils can be obtained, when the transition of rope from layer to layer at the left rim of the drum will be equivalent to transition at the right rim. It can be fulfilled, when rope during the transition from the last coil of previous layer to the first coil of next layer will made a pitch equal to half diameter of rope towards the and will adhere to it. This is achieved by the termination of coils of the first layer at a distance equals to a half diameter of the rope from the rims of the drum. Each layer starts at the rim of the drum and it is terminated by upwards movement and displacement in the rim direction, to form the first coil of the next layer. Coils arrangement is the same as in the previous pattern [13, 14].

5.3a *The multi-layer winding of rope in parallel grooves with one transition of skew grooves in the circumference*

In this method of winding, the coil of rope winds parallel to rims and during each rotation of the drum makes a singular skew displacement of one pitch to next rope's groove. Uplift of rope to the next layer with simultaneous recurrence takes place during directing of rope from the rim to the middle of wounding zone (fig. 5.7).

For this type of winding requirements are as follows [7, 13, 14]:

a. The pitch of rope grooves, t, can equals up to 1.1 of the diameter of rope, d, and the depth of groove, h, minimum 0.25 of the diameter of rope,
b. Introduction of rope from drum is distant from the right or left rim by a pitch of rope grooves measuring from the edge to the axis of rope, and is located directly behind the skew grooves towards the direction of wounding. Gap equal to a half of diameter of rope between the rim and the first coil has to be filled by insert to the height of winding diameter of the second layer.
c. Winding width of drum B (spacing between rims) has to be selected according to total number of rope coils, z, in the layer increased by a half of coil. In the new drums there has to be selected proper winding width on the stage of design. In the operating drums or at the replacement to the rope of different diameter matching is performed by the putting the filling inserts at the rims or at one of rim to the height at least of 1.5 of diameter of rope above the axis of rope of last layer.
d. Experimentally it was established, that the length of the skew grooves, l, measured at the circumference of the drum, parallel to the rims, should equals to about 2/3 d^2. In respect of

implementation, recommended length of skew grooves should equal to multiplicity of lining's width rounded up.

e. Directing wedges are made for rationatization of rope transition to subsequent layer. There are placed at rims in the zone of skew grooves. Height of wedge with scarf of 15° angle has to be equal to at least 1.5 of diameter of rope above the geometrical axis of rope of last layer. Edges of wedges can be cut, and sharp edges should be blunted.

f. Filling inserts are placed in the zone of skew grooves at the rim opposite to rope exit from the drum and they uplift rope from the first layer into the second one. Height of the inserts changes from the level of first layer to the level of the second layer. Inserts in the zone of skew grooves at the exit of rope from the drum and inserts in the zone of parallel grooves support the coils of second layer. Inserts can be made totally with drum linings, properlu shaping the lining at the rims or as segements. Filling inserts and directing wedges are made of hard wood, aliminium, textolit, plastics or steel. Depending on the material used, they are fixed to the rim, linings or to the shell of drum, by screws, tap bolts, and steel one can be welded.

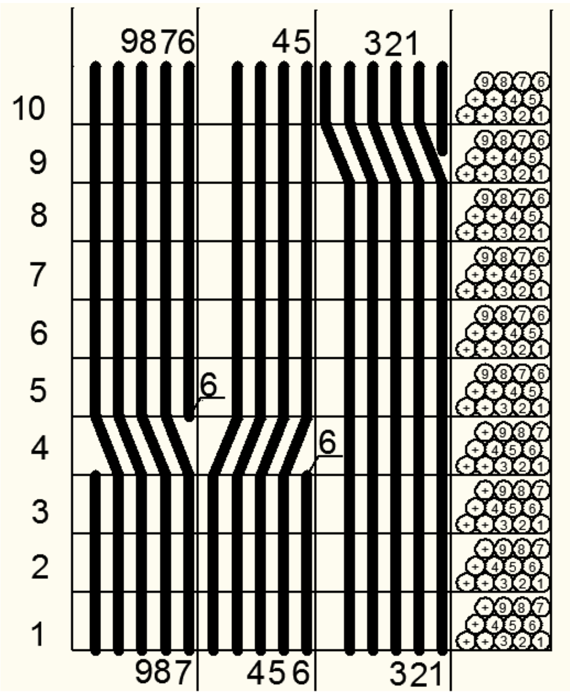

Fig. 5.7 Development of surfaces of winding of drum's lining with parallel grooves and one skew transition [14]

5.3b *Multi-layer winding of ropes in parallel grooves with two transitions of skew grooves in circumstance of the drum using lebus method*

In 1937, Frank LeBus patented the idea of a special grooving of drum lining, which properly guided the rope during its winding on a drum. This method was developed in 1950, and in technology it bears the name of the method LeBus. Frank LeBus was a producer of drilling rigs for the oil mining in Texas. The experiences with difficulties which occurred during winding multiple layers of rope on drums of drilling rigs, led to patent the new LeBus method, which started to be applied also in other types of winders including mining shaft hoisting. In mines in USA and South Africa, there began to use the LeBus grooving method during the winding multiple layers of ropes on cylindrical drums since 1962 [2, 4, 8, 12, 16].

In LeBus method grooves (fig. 5.1c, and 5.8) are made parallel to the rims and the displacement of coils along the drum by one pitch is obtained by performing skew grooves in two zones on the circumference of the drum, shifted from each other by 180°. With such grooved rope moves by a half pitch in one zone, thereby reducing the hitting of rope in the place of crossing and the possibility of excessive vibrations. Such grooving of LeBus method called synchronous is particularly useful for winding of mining vessels with a high speed, during multi-layer winding of more than three layers. Currently this way of grooving, LeBus synchronous, is the most popular method. To avoid synchronization of rope's jerks and vibrations during rotation of the drum, and to reduce the amplitude of harmonic vibrations (resonance of rope), there was done modification of the LeBus method (fig. 5.8b). It involves change in the displacement angle φ of skew grooves from 180° to (150° and 210°), (163° and 197°), or any other combination, which gives the sum of 360°. This method of grooving of lining was called LeBus asynchronous, and it is also widely used (fig. 5.8b).

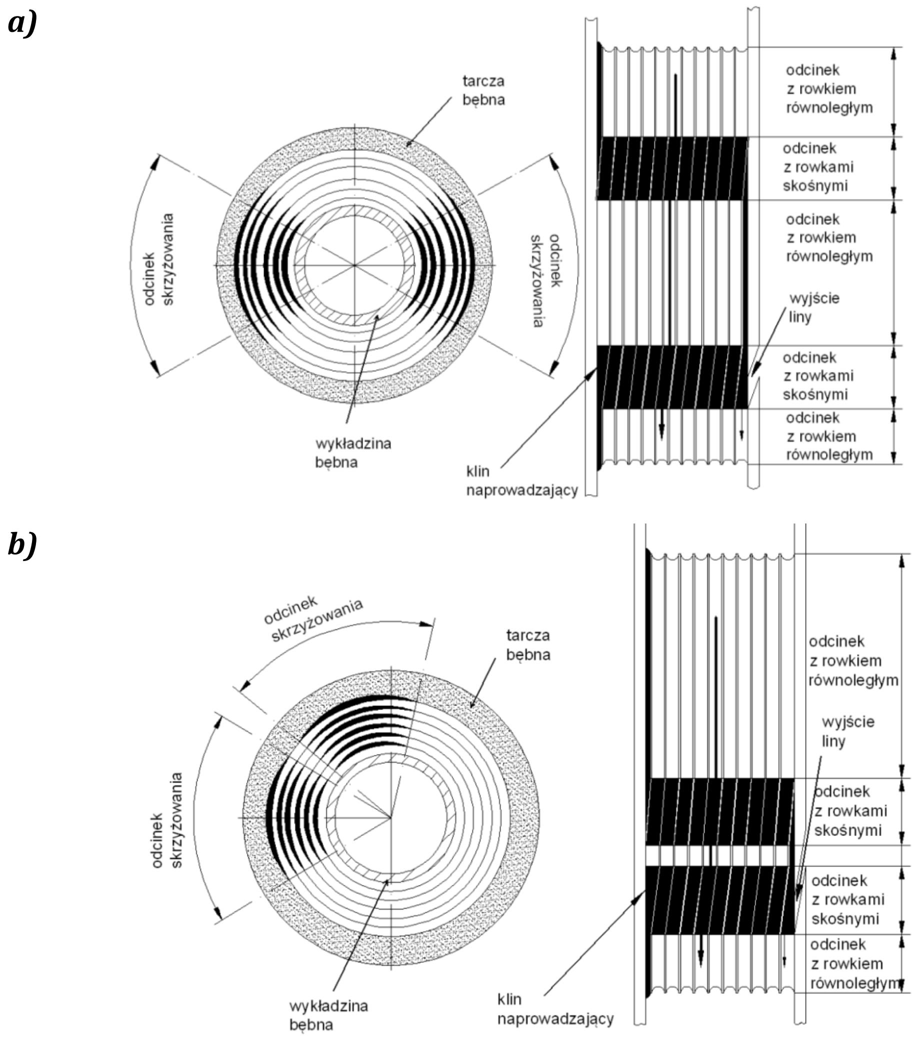

Fig. 5.8 Schemes of multi-layer winding of ropes on the drums of LeBus method [14]: **a) synchronous, b) asynchronous**

A necessary condition for satisfactory operation of the machine with multi-layer winding of ropes on drum is regular, smooth, compact and ordered winding of rope, both in the first and in subsequent layers. If the winding is irregular, then there is a possibility that rope will break through the wound layer and will place on lower improper layer. Also there is possibility of rope wedging at the rims of drum, what causes in rope occurrence of strong jerks, transmitting on the mining vessel, and causes its vibrations.

As a result of rope wedging and vibrations caused by transition of rope from layer to layer and from coil to coil, the durability of the rope decreases, as the result of wearing and cracking of wire. It should be noted, that compact and ordered winding of the first layer of rope in lining grooves influences on the proper winding of the subsequent layers, and thereby for the safe exploitation of the shaft hoisting.

5.3c *Parallel winding with two skew transitions in circumstance of the drum using synchronous LeBus method*

In the LeBus method coils of rope wind parallel to the rims and during each rotation of the drum perform double skew displacement of a half pitch *t* to next rope's groove. Uplift of rope to the next layer take place in a zone of skew grooves situated next to the exit of rope from a drum. Return of rope from the rim to the middle of wound zone (without uplift the rope) takes place in second zone of skew grooves.

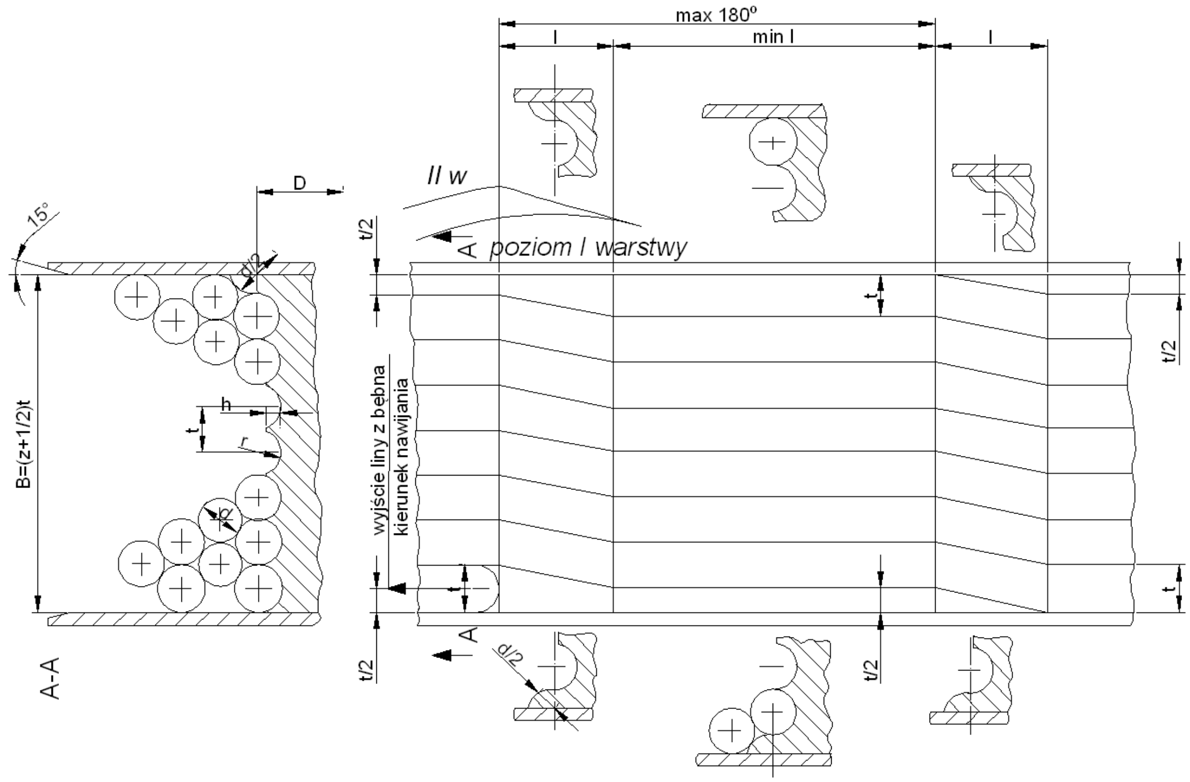

Fig. 5.9 Winding, using the synchronous LeBus method [4]

In zone of skew grooves situated next to the exit of rope from the drum, next to the opposite rim, inserts uplift the rope from the first to the second layer, and height of these inserts is changeable from the level of first layer to the level of second layer. However, inserts situated next to rim of the rope's exit from the drum, have changeable height from the level of second layer, to the level of third layer. Inserts situated in a second skew zone having an equivalent height, equals the level of second layer. Inserts can be made as complete with the lining of drum or in the form of segments [14].

In a fig. 5.9, there is presented a cross-section through a wound layer and the development of a drum. The grooves which are parallel to the rims, are made on the entirely circumstance of drum, with the exception of already mentioned two areas of the skew grooves. The skew grooves joint the parallel grooves situated shifted each other by a half pitch of groove *(d+ε)/2*.

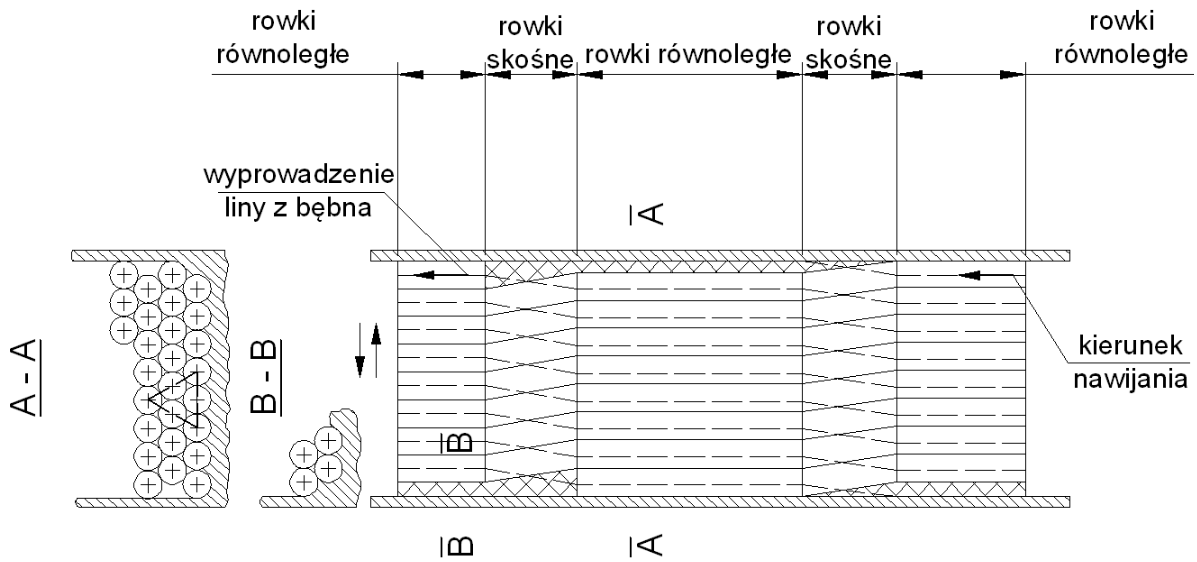

Fig. 5.10 The development of rope marks and cross-section of wound layers in LeBus synchronous method [4]

Directly at the rims of the drum there are situated filling inserts, which are used to support the extreme coils of the second layer, as indicated in a fig. 5.10 by a double hatching. Grooves are connected with filling inserts by mild transitions made in the same circumstance of drum as the skew grooves. Filling inserts reach a maximum height in the area of parallel grooves. During one rotation of a drum, rope will move twice about the half of rope diameter, so totally about one diameter. During the first skew displacement of the first coil of each layer, rope departs from the rim of the drum and when the last skew displacement of the last coil of each layer coming to the rim, then rope places parallel and adheres to the rim. Cross-section through the layers shows, that rope arranges in a pyramid-shaped columns, which ensures rope stability during the winding and the absence of side movements.

From the literature review it concludes, that the rope grooves (fig. 5.9) should be made according to following rules:

a. The total pitch of grooves *t* can equal to maximum 1.1 diameter of rope *d*, and depth of groove, *h*, minimum 0.25 of rope diameter.
b. Winding width of drum B (spacing between rims) has to be selected according to total number of rope coils, *z*, in the layer increased by a half of coil. In the new drums there has to be selected proper winding width on the stage of design. In the working drums or at the

replacement to the rope of different diameter matching is performed by the putting the filling inserts at the rims or at one of rim to the height at least of 1.5 of diameter of rope above the axis of rope of last layer

c. Output of rope from the drum is located at the left or right rim, that a rope adheres to the rim. The output of rope is located directly behind the skew grooves which uplift the rope to the next layer towards the winding of rope. Gap equal to half of diameter of rope (exactly half of pitch of rope groove) between the opposite rims and the last coil of first layer is filled with an insert at the height of level of second layer. In the second zone of parallel grooves gap, equal to half of diameter of rope, is laid near the rim of exist of rope from the drum, *i.e.* opposite than in the first zone.
d. Company LeBus states, that the length of the parallel grooves should be equal to about 80% of the circumference of a drum, and the total length of the skew grooves to about 20%.
e. Filling inserts are placed in a zone of parallel grooves to support the extreme coils of the second layer. Height of these inserts equals to the level of second layer.
f. The filling inserts are placed in the skew grooves area next to rim of the opposite output of rope from the drum and uplift the rope from the first to the second layer. The height of wraps is changing from level of the first layer to level of second layer. Inserts in the zone of skew grooves at the output of rope from the drum and inserts in the zone of parallel grooves support coils of second layer.
g. In order to obtain a good winding of rope, during an installation of rope it should be winded on the drum with an initial tension corresponding to 2% of force breaking the rope or with a tension corresponding to 10% of rope exploitation load.
h. Fleet angles of rope to the rope pulley should equals from 0.3^{o} to 1.5^{o}.
i. In the LeBus method high requirements are given regarding the geometrical dimensions of grooves and tolerance of diameter of rope.

SUMMARY

From the literature review it results, that the most profitable of all the methods of multi-layer winding of ropes on drum, due to the durability of a rope, its compact laying, and reduction of vibrations, is the synchronous LeBus method, or its modification, LeBus asynchronous.

At this moment these methods of multi-layer winding of ropes are widely used in global technique. Beside the rock and oil mining, there are used also in other domains *e.g.* cranes, transport machines in harbors, ships, offshore drilling platforms.

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Abstract: *In paper development of methods of multi-layer winding of ropes on cylindrical drums of mine hoisting machines (winders) was presented. Methods of winding ropes on smooth drums and drums with grooved linings were discussed. There was presented helical and parallel winding of ropes, and the most preferred in global technique of winding of ropes on drums with LeBus lining in synchronous LeBus version, and asynchronous LeBus version, in which the grooves are incise on sections, as parallel and skew grooves. Based on the literature review and experience in use of different methods of multi-layer winding of ropes, especially of LeBus method, abroad and in country, general requirements for their use are presented*.

Key words: *winding of ropes, LeBus method, testing of wire ropes*

ZAGADNIENIE WIELOWARSTWOWEGO NAWIJANIE LIN NA BĘBNY GÓRNICZYCH WYCIĄGÓW SZYBOWYCH

Streszczenie: *W opracowaniu przedstawiono rozwój metod wielowarstwowego nawijania lin na bębny cylindryczne maszyn górniczych urządzeń wyciągowych. Omówiono metody nawijania lin na bębny gładkie i bębny z wykładzinami rowkowanymi. Przedstawiono nawijanie lin spiralne, nawijanie równoległe oraz najbardziej preferowane w technice światowej nawijanie lin na bębny z wykładziną LeBus w wariancie LeBus synchroniczny i LeBus asynchroniczny, w których rowki są nacięte odcinkowo jako rowki równoległe i skośne. Na podstawie przeglądu literatury oraz doświadczeń w stosowaniu różnych metod wielowarstwowego nawijania lin za granicą i w kraju, szczególnie metody LeBus przedstawiono ogólne wymagania co do ich stosowania.*

Słowa kluczowe: *nawijanie lin, metoda LeBus, badanie lin stalowych*

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