

conveyor belt, bulk containers

**Maria ŁUSZCZKIEWICZ-PIĄTEK**

University of Łódź, Faculty of Mathematics and Computer Science  
Department of Applied Computer Science  
Banacha St. 22, 90-238 Łódź, Poland

**Czesław PYPNO\*, Janusz ŁUSZCZKIEWICZ**

Silesian University of Technology, Faculty of Transport  
Department of Logistic and Mechanical Handling  
Kraśińskiego St. 8, 40-019 Katowice, Poland

\*Corresponding author. E-mail: czeslaw.pypno@polsl.pl

## **EFFICIENT METHOD FOR STORAGE OF LONG CONVEYOR BELTS PASSAGES INSIDE THE BULK CONTAINERS**

**Summary.** The paper introduces the family of the algorithms designed to improve the process of winding up the long conveyor belt passages on reels located inside the bulk containers, used for i.e. rail transport. The proposed method provides the convenient storage technique of the long belt passages, enabling their transport on the standardized rail wagons. Presented solution also addresses the problems related with binding the smaller belt passages, such as shorter life span in comparison to the single-part belt. Moreover, the presented work contains not only the details of the two algorithms representative for the proposed method, but also the outlook of the system of the automatic control required for the successful application of the proposed technique.

## **METODA GROMADZENIA DŁUGICH ODCINKÓW TAŚM PRZENOŚNIKOWYCH NAWINIĘTYCH W KASETACH**

**Streszczenie.** Artykuł przedstawia rodzinę algorytmów zastosowanych do długich odcinków taśm przenośnikowych nawijanych na bębny w kasetach przystosowanych do transportu szynowego. Zaproponowana metoda przedstawia sposób gromadzenia długich odcinków taśm przenośnikowych na typowych wagonach kolejowych. Prezentowane rozwiązanie pozwala wyeliminować problemy związane z łączeniem krótkich odcinków taśm w całość. Ponadto w pracy przedstawiono oprócz dwóch dokładnych algorytmów proponowanej metody także pogląd na system automatycznego sterowania przedmiotowego rozwiązania.

### **1. INTRODUCTION**

The bulk conveyors as a means of transportation are irreplaceable in mining and related industry. Thus, it is crucial to develop and introduce any improvements leading to their increased efficiency, safety and cost reduction. The important problem related with the bulk conveyors use is the method of binding the passages of the belts. The technique applied for that purpose may influence the overall

time and the cost of the conveyor assembling [1,3]. Therefore, the less parts of the belt are required to combine, the less time consuming the process is. Moreover, the fact that belt is combined of several shorter passages has grave implications due to the increased vulnerability of binding area to rupture or other damages resulting in forced outage of conveyor. The process of winding up the belt parts on several reels requires also the use of the specific engines of custom design with the automatic control systems.

## 2. PROPOSED ALGORITHM

The process of the belt winding (accumulation) on the bulk container reels can be described as a sequence of the following steps of the number related to the length of the belt passage and the number of reels. In order to place the belt inside the bulk container (see Fig. 1, 2) of total length denoted as  $3x$ , three reels must be used. The process is described by the following three-steps procedure:

1) At the beginning the engine of reel No.1 should be switch on (SIL-1:ON) to move clockwise ( $w_1 > 0$ ) as long as the length of the winded up (placed) belt will be equal to  $1,5x$ . Then, the engine automatically stops.

2) In the second phase, the engine of the reel No.1 is set to move counterclockwise ( $w_1 < 0$ ), resulting in unreeling (releasing) the belt. Simultaneously, the engine of reel No.2 is set on (SIL-2:ON) to move clockwise ( $w_2 > 0$ ). These settings are maintained till the length of the accumulated belt  $\delta_1$  of the reel No.1 will reach  $0,5x$  and that  $\delta_2$  of the reel No.2 will reach  $2x$ .

3) Finally, when the Phase 2 is completed, the reel movement direction is reversed again. Moreover, the engine No.3 is switch on (SIL-3:ON) to move clockwise. Thus, the engine No.1 moves clockwise ( $w_1 > 0$ ) while engine No.2 moves counterclockwise ( $w_2 < 0$ ). These settings are maintained as long as the length of the belt stored on all three reels will reach value of  $1x$ . When this goal is achieved, the control system turn off all engines (denoted as "OFF").

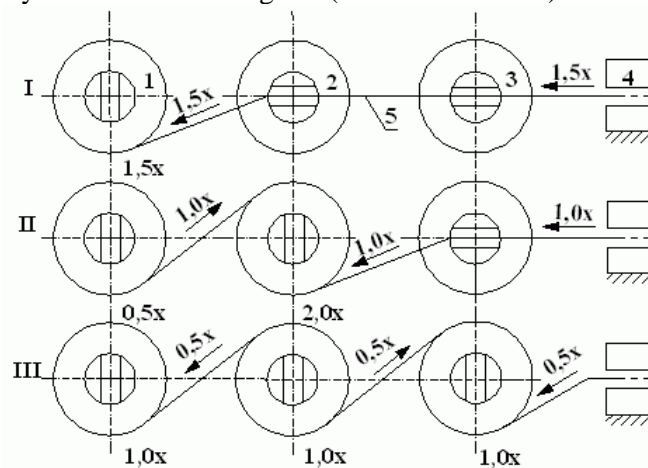


Fig. 1. Stages of the conveyor belt accumulation for 3 reel system: 1-3 – reels, 4 – vulcanization press, 5 – belt passage, I-III – the algorithm steps

Rys. 1. Fazy nawijania taśmy w kasecie z trzema bębni: 1-3 – bębny do nawijania taśmy, 4 – prasa wulkanizacyjna, 5 – taśma, I-III – kolejne fazy nawijania bębnow

Let us note that is case when each reel, according to the given algorithm, is not moving, the belt can freely pass through. However, when the reel starts the accumulation process, the belt is anchored inside. Moreover, the reel (denoted as 1) should be constructed is such a way that it is physically possible to store a belt passage of length of  $1,5x$ , which is required in first phase of the proposed algorithm (see in Fig. 1). The second reel (2) in the second phase of the algorithm should be able to store belt passage of length equal to  $2x$ . Finally, the third reel is required to store passage of length of  $1x$ . The choice whether reels are the same capacity (i.e.  $2x$ ) or not, may depend on the other specifications or requirements.

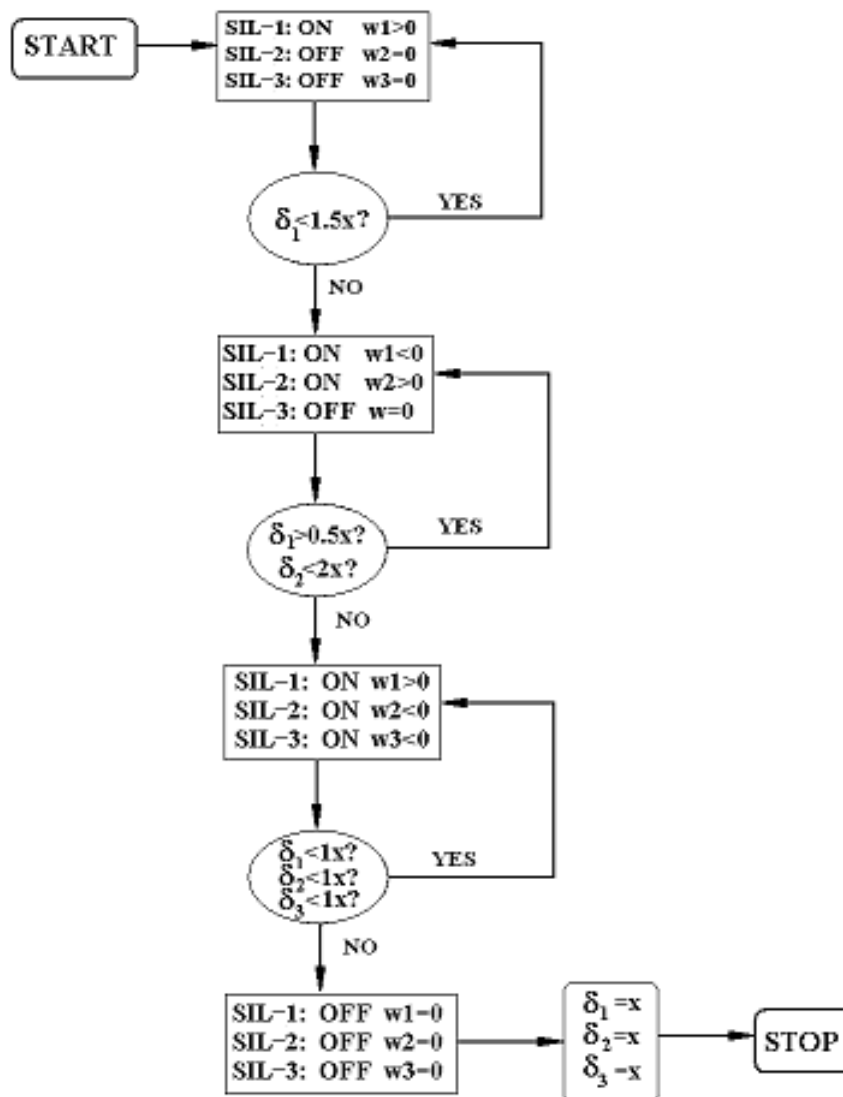


Fig. 2. The block diagram illustrating the process of belt accumulation in 3-reel system: SIL1÷3 – engines,  $w1÷3$  – operation mode engines (clockwise  $w>0$  or counterclockwise  $w<0$ ),  $\delta_{1÷3}$  – accumulated belt of the reels 1÷3,  $x$  – the length of accumulated belt passage

Rys. 2. Schemat blokowy algorytmu nawijania trzech bębnow w kasecie: SIL1÷3 – silniki,  $w1÷3$  – sposób pracy silników (zgodnie z kierunkiem ruchu wskazówek zegara  $w>0$  lub przeciwnie do ruchu wskazówek zegara  $w<0$ ),  $\delta_{1÷3}$  – nawinięcia na bębnach 1÷3,  $x$  – długość odcinka taśmy

### 3. CONTROL SYSTEM

The theoretic time course plots (see Fig. 3) of belt accumulation and release (winding process) provide the graphical illustration of the method presented in this paper. The figure depicts the work mode of the set of the engines subjected to the following constraints: overshoot (over the actual reference value of the required accumulation), oscillation or sudden changes of reel speed should not be observed during the process.

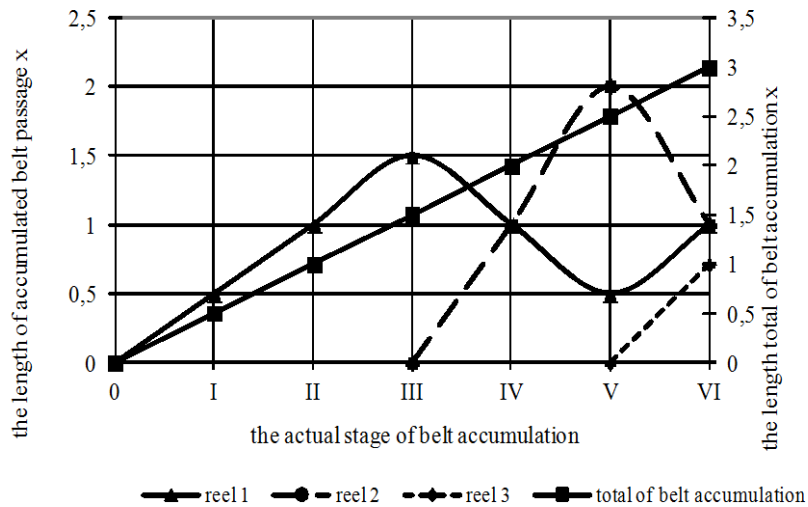


Fig. 3. The theoretical time course of belt accumulation process for 3-reel system, I-VI – the algorithm steps  
 Rys. 3. Teoretyczne przebiegi czasowe nawijania taśmy na trzy bębny, I-VI – kolejne fazy nawijania bębnow

The physical realization of the proposed solution cannot be achieved without the incorporation of the control system responsible for maintaining the proper work of the system according to the algorithm described in Section 2. Therefore, the algorithm commands must be translated to appropriate control signals of engines of each reels. Thus, the regulation process using control signals evaluated by the controllers must assure stable work of mechanism, without overshoot and oscillations, resulting in temporary accumulation of more belt than it is required in actual algorithm stage or sequential accumulation and releasing in process of the approaching the reference value for accumulated belt. Both situations should be avoided when safety and effectiveness of the process is taken into account. Moreover, all other mechanical elements are also exploited severely during such a work mode, influencing their lifetime as system parts [2, 4].

For the purpose of the solution proposed in this paper, the reels can be treated as multi-inertial objects, specifically in simplified version of two-inertial objects. As regulator type, the PI (proportional-integral) was chosen, with parameters enabling stable work with no overshoots and sudden changes of control signals deciding about behavior of the reels.

The system works in following manner: switching on and off of the engines are executed according to the proposed algorithm, but the particular control signals are evaluated by regulators (PI) on the basis of the real time information concerning the actual level of belt stored on each of the reels in comparison to that expected in the actual stage the algorithm. Taking into account that information, the regulator incites the increase (just after engine start) or the decrease (when amount of belt passage is close to expected) of the speed of winding the belt, in order to provide efficient work and to avoid sudden changes of system operation mode.

## 4. SCHEMATIC CONSTRUCTION OF THE CONTROL SYSTEM

### 4.1. Three reel system

The automatic control system designed for the solution presented in this paper is comprised of three PI (proportional-integral) regulators, each working with associated object (OB1 or OB2 or OB3) (reels). Additionally, there is also a measurement unit monitoring the rate of belt accumulation on each reel in relation to the actual stage of the algorithm. The schematic structure of the system is shown in Fig. 4. For example, if in the actual stage of the algorithm one or more of the engines should be switch off, the expected value of accumulation on a reel is set to be 0 assuming that the accumulation is

started when reels are empty with no belt on them. The amount of accumulated belt of each reel is compared continuously with the expected value at the current stage of algorithm, and their difference is sent to the PI regulators. The measured error is the basis for the evaluation of the new control signals. This procedure is repeated as necessary, till the algorithm is completed, i.e. when all of the belt accumulations on reels will be equal to those indicated by the algorithm. In order to meet safety requirements and assure stable work i.e. continuous belt winding after forced delay, pause or previous errors in the process, the proposed solution should be supplied with the correction mechanism, e.g. procedure of complete releasing the belt from all of the reels.

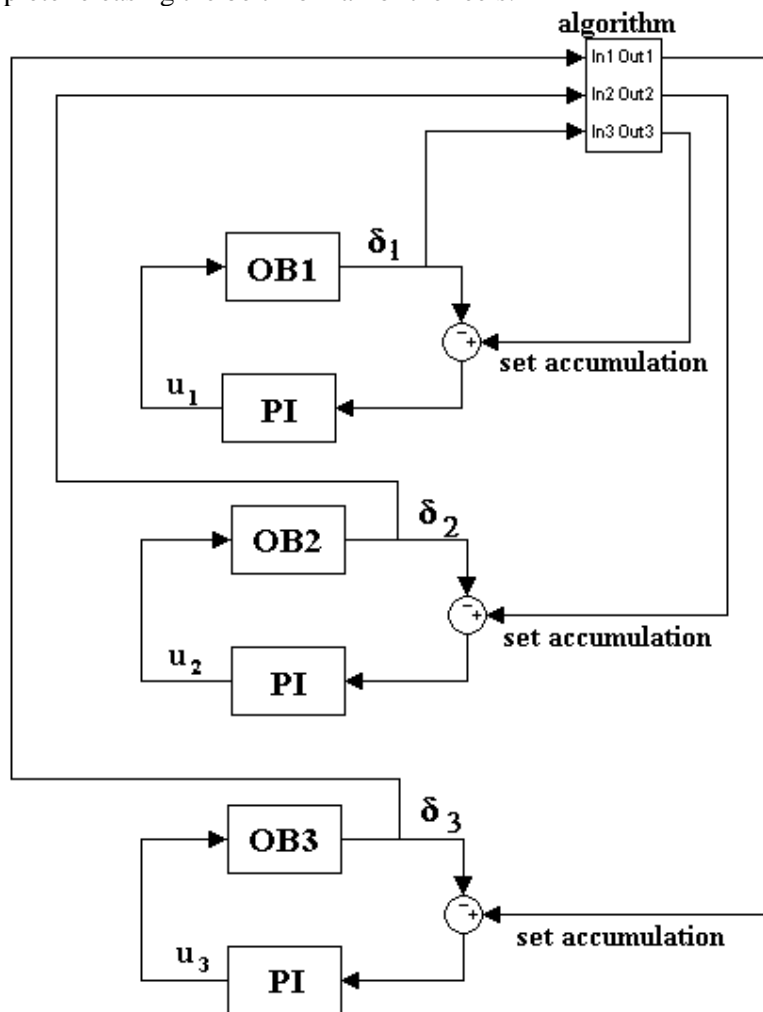


Fig. 4. The schematic construction of the automatic control system applied in proposed 3-reel solution: PI - regulator proportional – integral, OB1÷3 – objects of the reels 1÷3,  $\delta_{1\div3}$  – accumulated belt of the reels 1÷3,  $u_{1\div3}$  – set value of the reels 1÷3

Rys. 4. Schemat sterowania 3 bębniami w kasecie: PI – regulator proporcjonalno-całkujący, OB1÷3 – obiekty bębnow 1÷3,  $\delta_{1\div3}$  – nawinięcia bębnow 1÷3,  $u_{1\div3}$  – wartość zadana bębnow 1÷3

#### 4.2. Five-reel system

The algorithm proposed in the previous Section can be modified in case of the transport of the longer belt passages. Naturally, it is not possible to transport every belt passages using the three-reel system. The first and the most important constraint is related with the bulk container size, which must be compatible with flat wagons used for transport. Therefore, the choice of the particular algorithm of the family presented in this paper must be motivated by the belt passage length. In case of belts longer than those analyzed in previous Section, the five-reel algorithm can be applied, providing the possibility of the convenient transportation of the belt passages of length of  $5x$ . Let us note that the

belt length denoted as  $1x$  is strictly bounded to the reel and the bulk container capacities. Moreover, it also critically depends on the size of the flat wagons used for transportation.

The proposed technique is shown in Fig. 5. Let us note that although this procedure requires  $X$  steps, it also assures that in each step the maximum length of the belt on particular reel do not exceed  $2x$ . Thus, the more stages of the algorithm, the smaller radius of each reel and its' maximum capacity is the required (Fig. 6).

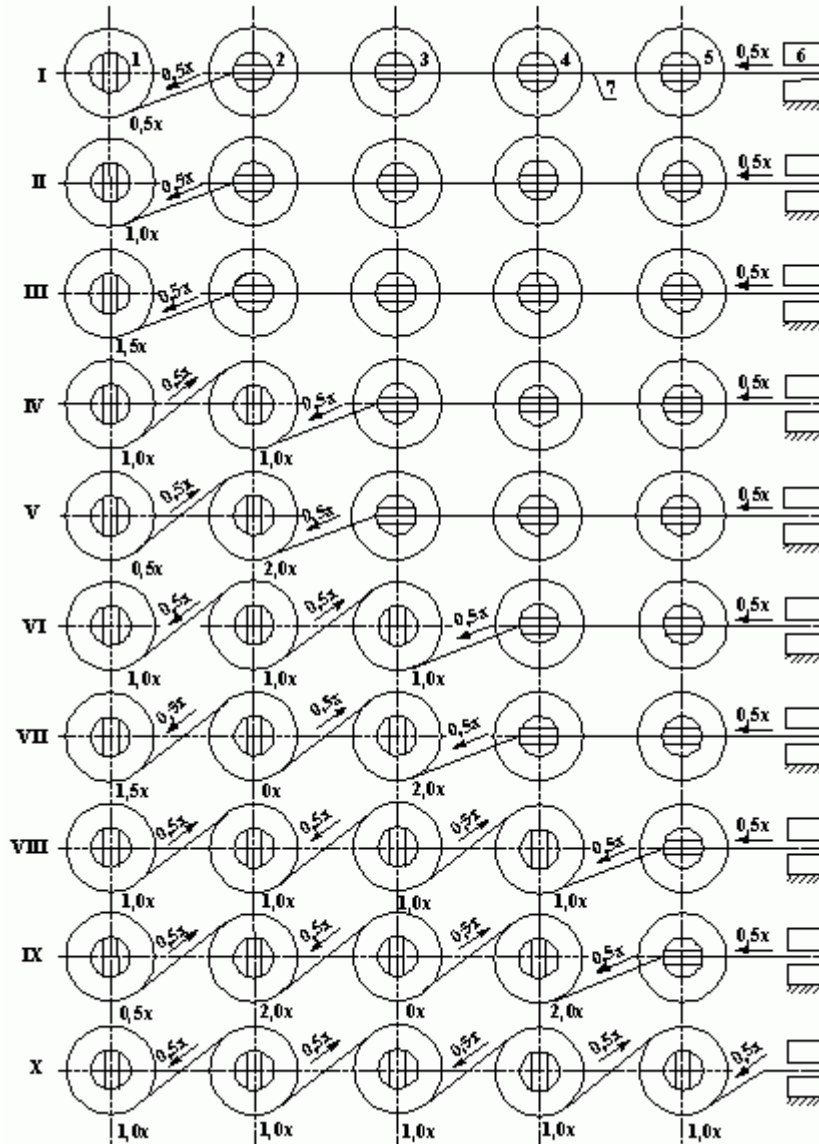


Fig. 5. Stages of the conveyor belt accumulation for 5 reel system: 1-5 – reels, 6 – vulcanization press, 7 – belt passage, I-X – the algorithm steps

Rys. 5. Fazy nawijania taśmy w kasecie z pięcioma bębniami: 1-5 – bębny do nawijania taśmy, 6 – prasa wulkanizacyjna, 7 – taśma, I-X – kolejne fazy nawijania bębnow

Fig. 7 illustrates the theoretical time course plots of the winding process for 5-reel configuration. Moreover, the reconstruction of the algorithm stages for each reel is possible on the basis of the provided plots. Let us note that process of accumulation and release is synchronized.

The physical realization of the system of the automatic control for the configuration of the five reels is also based on use of PI controllers working with each of the objects: OB1, OB2, OB3, OB4, OB5 (see Fig. 8). The general rules governing the work of this system are analogous to those concerning the three-object configuration.

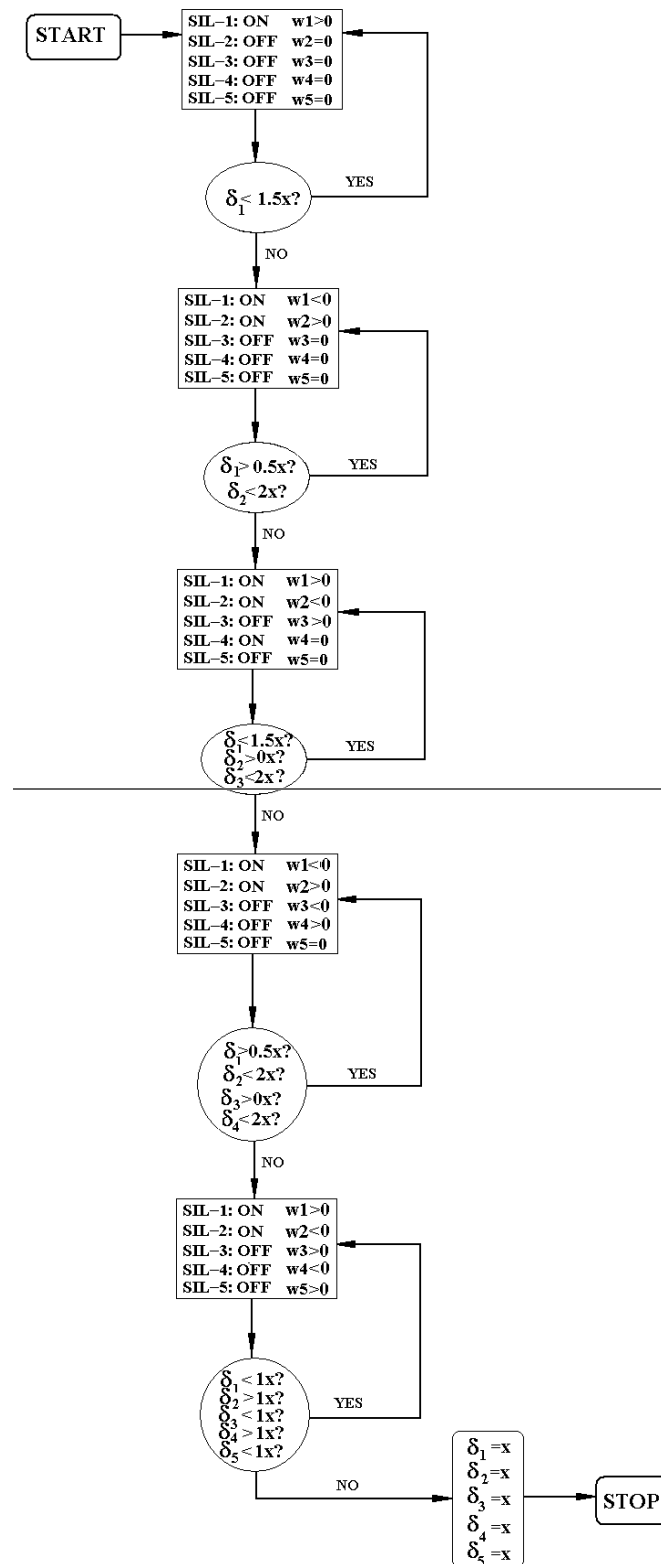


Fig. 6. The block diagram illustrating the process of belt accumulation for 5 reel system: SIL1÷5 – engines, w1÷5 – operation mode engines (clockwise w>0 or counterclockwise w<0),  $\delta_{1\div5}$  – accumulated belt of the reels 1÷5, x – the length of accumulated belt passage

Rys. 6. Schemat blokowy algorytmu nawijania pięciu taśm w kasecie: SIL1÷5 – silniki, w1÷5 – sposób pracy silników (zgodnie z kierunkiem ruchu wskazówek zegara w>0 lub przeciwnie do ruchu wskazówek zegara w<0),  $\delta_{1\div5}$  – nawinięcia na bębnach 1÷5, x – długość odcinka taśmy

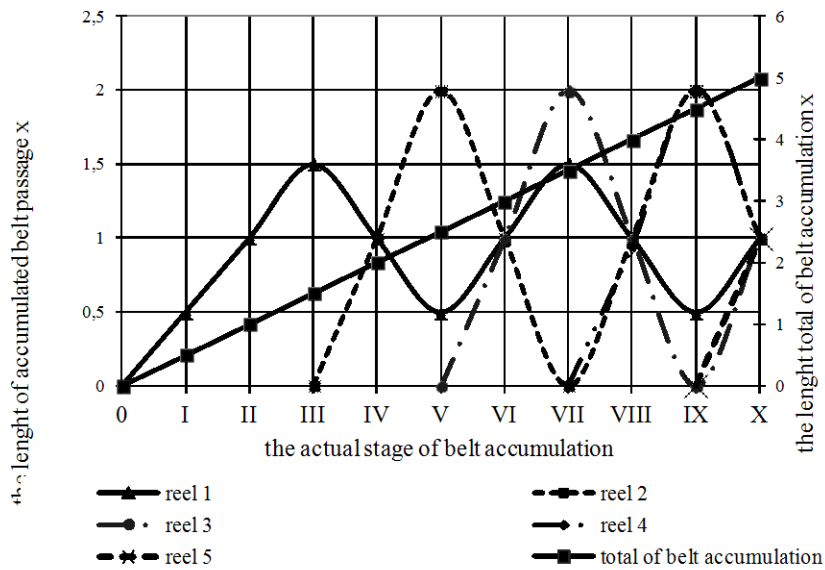


Fig. 7. The theoretical time course of the belt accumulation process in 5-reel system  
 Rys. 7. Przebiegi czasowe nawijania taśmy w kasecie z 5 bębniami

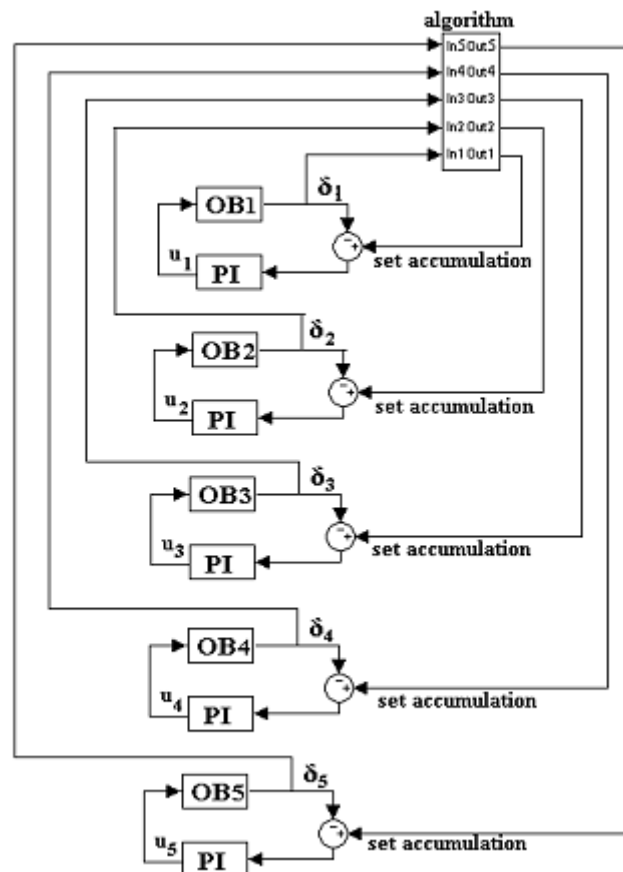


Fig. 8. The schematic construction of the automatic control system applied in proposed 5-reel solution:  
 PI – regulator proportional-integral, OB1÷5 – objects of the reels 1÷5,  $\delta_{1+5}$  – accumulated belt of the reels 1÷5,  $\delta_{1+5}$  – set value of the reels 1÷5

Rys. 8. Schemat sterowania 5 bębniami w kasecie: PI – regulator proporcjonalno-całkujący, OB1÷5 – obiekty bębnow 1÷5,  $\delta_{1+5}$  – nawinięcia bębnow 1÷5,  $\delta_{1+5}$  – wartość zadana bębnow 1÷5



## 5. SUMMARY

The presented paper describes efficient procedure which provides convenient method for the storage of the long passage of the belt conveyors on several reels. Therefore, it is possible to transport longer continuous passages of the material than before, as a single load. This is crucial because of the fact that such an approach eliminates the need for binding the smaller parts of belts together, usually associated with the faster belt deterioration during exploitation. Moreover, the ruptures in binding area are possible, causing forced maintenance pauses, and thus increasing the exploitation costs. The proposed solution not only defines the family of methods enabling the storage of the long belt passages on reels, but it also postulates the safety precautions in order to assure stable work of the proposed system. The method can be realized using 3 or 5 reels system with PI regulators enabling stable and efficient work.

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