

The Analysis of Effectiveness of Conveyor Belt Tensioning Systems

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INTRODUCTION

The growing importance of belt transport in industry has caused increased interest of users, designers and scientists in the problems of belt conveyor efficiency (Antoniak 1990, Gładysiewicz, 2003). In simplified terms, the efficiency of the belt conveyor and any other means of transport can be defined as the ratio of the effect obtained, i.e. the product of the transported mass of material M and the length of transport path L , to the costs of obtaining it, i.e. the sum of K_{INW} and operating expenses incurred ($K_{EN}+K_{NA}+K_{PA}+K_O$). The efficiency of each means of transport is related to a specific period of its work and, in principle, it should be considered throughout its entire planned life (Król et al., 2017).

$$E_T = \frac{M \cdot L}{K_{INW} + (K_{EN} + K_{NA} + K_{PA} + K_O)} \quad (1)$$

where:

M - mass of transported material [t],

L - length of transport path [m],

K_{INW} - purchase costs [\$],

K_{EN} - electricity costs [\$],

K_{NA} - costs of planned repairs and renovations [\$],

K_{PA} - costs of removing failures and incurred losses [\$],

K_O - staff costs [\$].

One of the basic components of the belt conveyor is the belt tensioning system. Its main task is to ensure trouble-free operation of the frictional power transmission system on the belt and to maintain proper belt overhang along the entire conveyor route. The evaluation of the efficiency of the belt tensioning device is complex, because this system is not autonomous and is only an element of the belt conveyor equipment (Kulinowski, 2012). Therefore, the assessed and measurable effect of the tensioning device is the same as the overriding effect associated with the output process, i.e. the product of the weight and transport path of weed (1). Improving the efficiency of tensioning

devices can be achieved by reducing the cost of purchasing the device, energy used to stretch the belt and by reducing the number of people operating the device. From the point of view of the full life of the conveyor belt, the most significant costs are incurred due to repairs and replacements of belt sections, costs related to unplanned stoppages of the haulage and costs of failure removal. Reliability and durability of belt conveyor components have a significant impact on this cost group (Antoniak 1990, Żur 1996).

Elements of the belt conveyor such as: belt, splices, drums and their bearings, ropes in the tensioning system, route, rollers are subjected to a complex load condition, which results from the conveyor operation characteristics (Gładysiewicz et al., 2017). The belt durability is influenced by many factors, on the one hand its quality, and on the other broadly understood operating conditions resulting also from the conveyor design. The reduced working time of the belt is often the result of fatigue phenomena, as the belt during work on the conveyor is subjected to many cyclic loads causing a complex state of stress in the heterogeneous structure of the belt (Bajda et al., 2016). Based on comparative analyzes, it is assumed that a reduction of tensile stress by 30% may result in a 6-fold increase in the life of the belt and its splices (Jabłoński, 1988). Therefore, from the point of view of improving transport efficiency by increasing the durability of the main components of the conveyor belt, it is important to adjust the value of the tensioning force to the changing conditions of the conveyor load (Hardygóra et al. 2012).

BELT TENSIONING SYSTEMS

Correctly functioning tensioning devices should react without significant time delays to changes in force in the belt and regulate it so as to maintain its minimum value necessary for the correct operation of the conveyor (Kulinowski, 2013A, Li, 2002, Zhang et al., 2010).

Among the tensioning devices used to tension the belt of mining belt conveyors, the following solutions can be mentioned:

- A. With a fixed position of the tensioning drum during conveyor operation.
- B. With variable position of the tensioning drum during conveyor operation.

To compare the operation of various tensioning devices, their selected features are shown in Table 1 (Kulinowski, 2012).

The static characteristics of various types of belt tensioning devices are presented below, with both fixed and variable position of the tensioning drum during conveyor operation (Fig. 1). Under no circumstances should the value of the tensioning force of the belt S_2 fall below the permissible level: S_{2R} during conveyor start-up, S_{2U} during steady-state operation and S_{2P} during conveyor standstill (Kulinowski, 2013B).

The diagram (Fig. 1) also includes the characteristics of automatic winch and gravitational tensioning systems, adjusted as a function of the conveyor's operating phase. Immediately before the conveyor is started, the tensioning force from S_{2P} to S_{2R} is increased, and after it is reduced to S_{2U} .

Table 1 Features of typical belt tensioning devices

Selected features of the operation of tensioning devices	Type of belt tensioning device in the conveyor			
	A	B		
	rigid	gravitational	automatic with regulation system	follow-up
Compensation of belt elongation during start-up	-	+	-	+
Compensation of belt elongation during steady motion	-	+	+	+
Compensation of thermal elongation of the belt	-	+	+	+
Adjustment of belt tension force as a function of drive torque	-	-	- / +	+

+ yes; - no; -/+ possible;

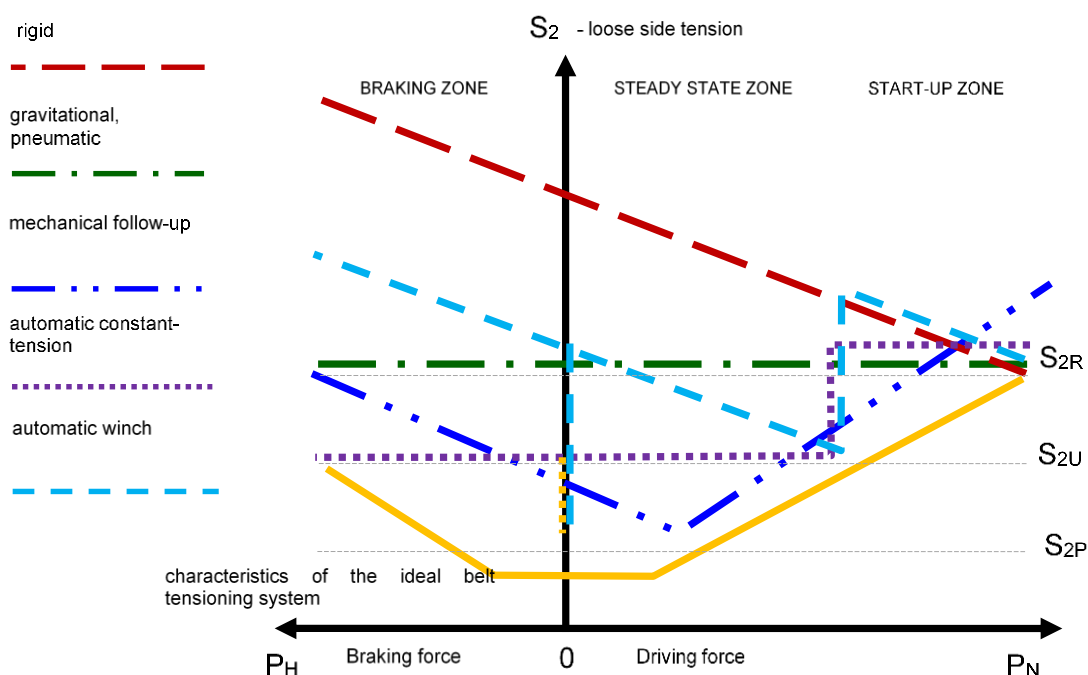


Fig. 1 Static characteristics of selected types of belt tensioning systems

Source: (Kulinowski, 2013A)

The characteristics of the tensioning devices presented above are only theoretical and their actual course requires testing on a real object that would allow reconfiguration and change of parameters of the belt tensioning system.

THE TEST STAND

The belt conveyor, which is used as a laboratory test stand, was made based on the theory of mechanical similarity, so that the results obtained on it can be applied to industrial objects (Furmanik et al., 2012).

The laboratory research conveyor is equipped with a system for monitoring its work, consisting of a series of sensors for measuring kinematic and dynamic parameters. Depending on your needs, the displacements and speeds of moving parts, such as tensioning carriages and the belt, are recorded. The values of forces occurring in the belt tensioning system are recorded, as well

as the values of reaction forces on the dropping and returning drum as well as the forces acting on the belt support system.

The load condition of the conveyor is controlled by a friction braking system, built-in on the upper belt - Fig. 2, item 5.

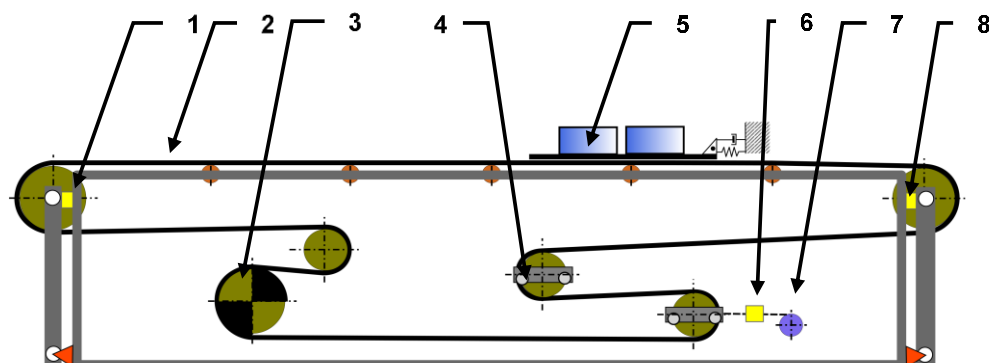


Fig. 2 Construction diagram of the laboratory test conveyor

- 1 - Force gauge on the dropping drum, 2 – Belt, 3 - Driving drum, 4 - Tensioning drum
5 - Conveyor loading system, 6 - Force gauge in rope, 7 - Winch
8 - Force gauge on the return drum

An important advantage of this test stand is the possibility of reconfiguring its drive system and belt tensioning. You can test a single and double drum system under various load conditions and examine the performance characteristics of various types of belt tensioning systems.

FOLLOW-UP BELT TENSIONING DEVICES

Construction of efficient and follow-up belt tensioning devices that meet the requirements, however, encounters difficulties. In transient states of the conveyor operation, the tensioning drum must be moved with variable value of speed and its direction, in terms of changing belt forces. The problem is in the temporarily large and variable power for the actuator (trolley with a tensioning drum), ensuring operation of the device without significant time delays. The instantaneous power values preclude, in principle, the use of this type of tensioning devices own drives and the chance is to use the main stream of mechanical power of the conveyor, i.e. the use of follow-up belt tensioning devices.

In the case of long conveyors, an interesting proposal is a proportional belt tensioning system with two tensioning trolleys located in the area of large and low forces in the belt (i.e. in front of and behind the drive drum). The tensioning trolleys are connected by a system of ropes with a fixed ratio, ensuring a constant ratio in the tight and loose side of the belt (Kasza & Kulinowski, 2014). A simplified diagram of the tensioning system with two tensioning trolleys is shown in Fig. 3.

For the purposes of testing various types of tensioning devices, the conveyor was equipped with a proportional follow-up tensioning system that can easily be replaced with a rigid winch by using a tensioning lever lock (Fig. 4).

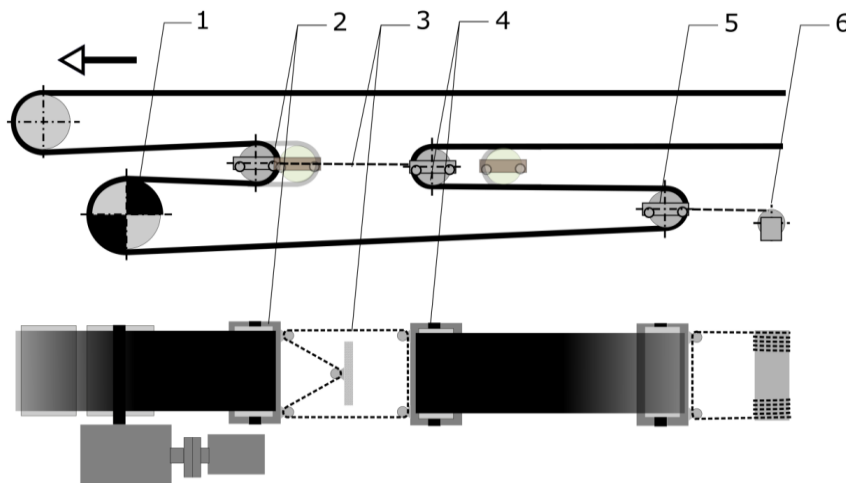


Fig. 3 Proportional, follow-up tensioning system with two tensioning trolleys

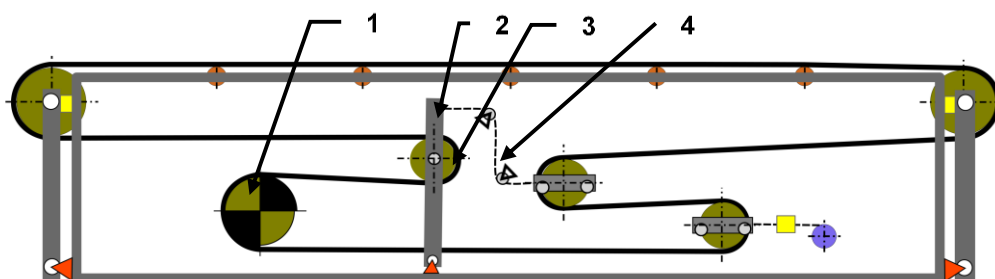


Fig. 4 Diagram of a laboratory conveyor belt tensioning system
 1 - Driving drum, 2 - Tensioning lever, 3 - Tensioning drum,
 4 - System of ropes

The photo in Figure 5 shows the view of the drive with tensioning lever. The drum of the high tension loop is connected by a lever-rope system with a ratio of 1:2 to the tensioning carriage of the low-tension loop. On the conveyor in front of the low-tension loop trolley there is a rope winch for adjusting the initial belt tension. After locking the tensioning lever with the high-tension loop trolley, the follow-up system becomes a rigid tensioning system.

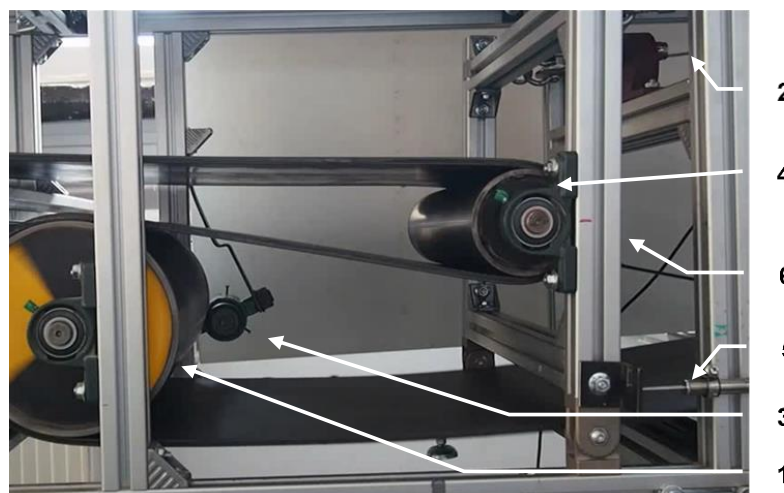


Fig. 5 Proportional follow-up tensioning device installed to laboratory belt conveyor
 1 - Driving drum, 2 - System of ropes, 3 - Speed sensor
 4 - Tensioning drum, 5 - Displacement sensor, 6 - Tensioning lever

PNEUMATIC BELT TENSIONING DEVICE

Another object of the described tests is a pneumatic belt tensioning device, which also has the ability to adjust the force acting on the tensioning drum depending on the changing operating conditions of the conveyor and its load. A pneumatic cylinder was used as the executive system, while a reducing valve with a pressure gauge was used to regulate the air pressure. At this stage of testing, adjustment of the tension force was carried out manually by changing the settings of the reducing valve with simultaneous control of air pressure.

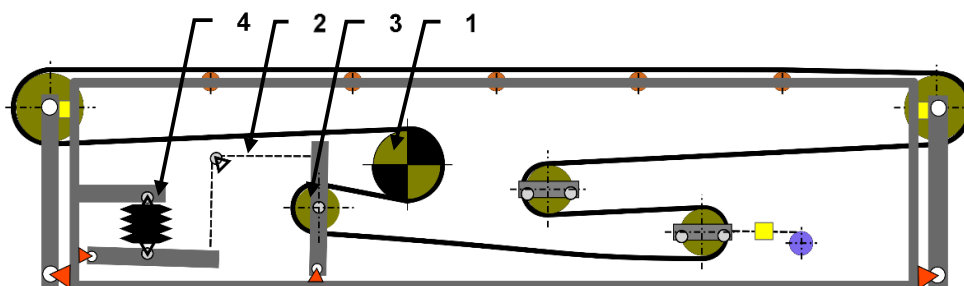


Fig. 6 Diagram of a pneumatic belt tensioning device
1 - Driving drum, 2 - System of ropes, 3 - Tensioning drum, 4 - Pneumatic cylinder

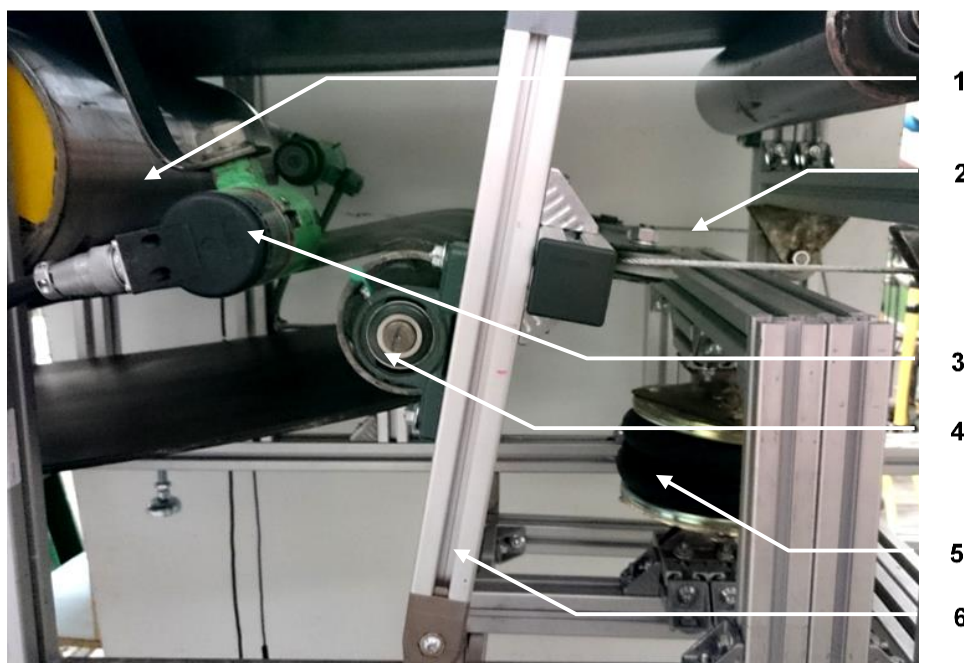


Fig. 7 Pneumatic tensioning device installed to laboratory belt conveyor
1 - Driving drum, 2 - System of ropes, 3 - Speed sensor, 4 - Tensioning drum
5 - Pneumatic cylinder, 6 - Tensioning lever

RESEARCH METHODOLOGY

Tensioning system tests were carried out for variable conveyor load as well as for starting and braking at variable load. The belt pretension has been selected so that the conveyor starts under maximum load and runs with the least possible slip. For the vfollow-up system, this force was about 270 N, while for the rigid system about 1000 N. For the gravitational and pneumatic belt tensioning system, a constant tension value of 700 N.

The measuring equipment of the conveyor made it possible to determine belt tension at the tight side and loose side of the drive drum, displacement of the tensioning trolleys and the speed of the drive drum and belt speed after it.

Comparative tests of tensioning systems: follow-up, rigid, gravitational and pneumatic were carried out in two sequences:

- full load start-up, gradual unloading, carried out in three stages and braking without load;
- no-load starting, gradual loading and braking at full load.

THE RESULTS

During the experiment, efforts were made to ensure a similar load condition of the conveyor with the belt braking system for all tested belt tensioning systems. Examples of changes in circumferential force on the drive drum, which is directly proportional to the belt resistance force, are shown in Fig. 8.

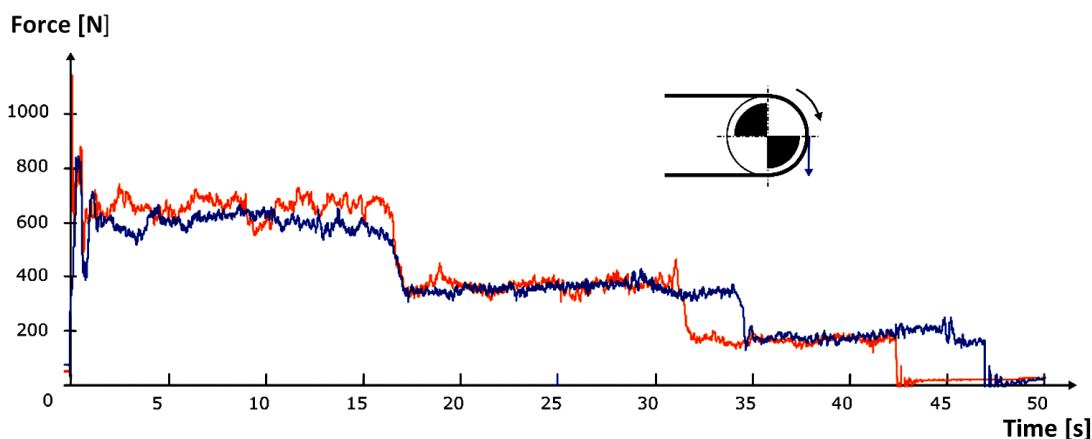


Fig. 8 The course of changes in circumferential force P on the drive drum for the follow-up and rigid tensioning systems

The force on the drum driving the belt causes a difference in force in the belt at tight side and loose side of the drum. The nature of the course of force changes in the belt depends on the tensioning device used. In the case of a proportional follow-up tensioning system, the force in the loose side of the belt increases in proportion to the increase in the driving force, which ensures the non-slip operation of the friction drive. However, when the conveyor is unloaded, the tensioning force decreases to the minimum value required due to the permissible belt sag (Fig. 9).

When a rigid belt tensioning system is used, the course of changes in the tensioning force values takes on a completely different character to the follow-up system. The value of the force in the loose side of belt increases as the value of the driving force decreases, and decreases as the load level of the conveyor increases (Fig. 10). Therefore, for the winch tensioning system (rigid), the value of the belt pre-tension force ($1000 \text{ N} > 270 \text{ N}$) was significantly increased to minimize the possibility of slipping on the steel surface of the drive drum.

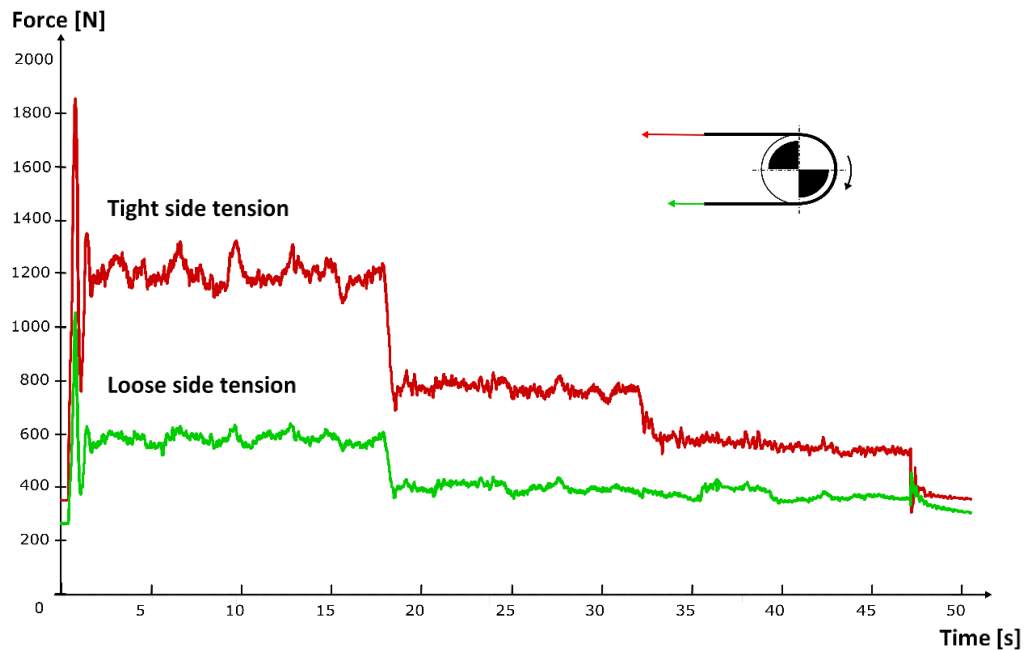


Fig. 9 The course of force changes on the tight and loose sides of the drive drum

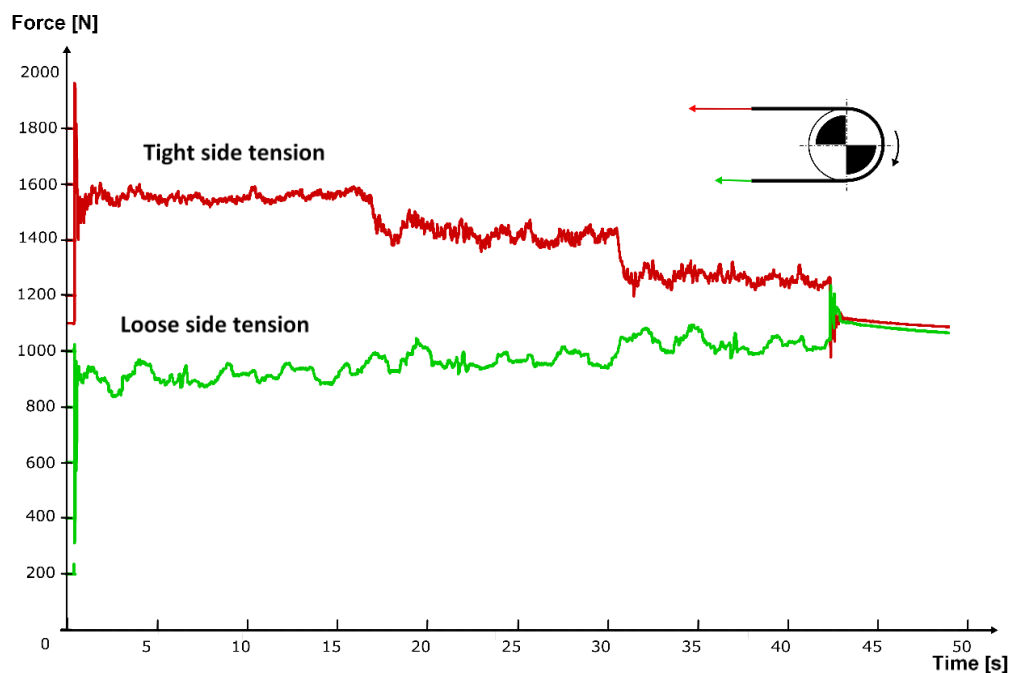


Fig. 10 The course of force changes on the tight and loose sides of the drive drum

In the case of the use of constant-tension belt tensioning systems: gravity and pneumatic, the value of at the loose side tension force remained constant, regardless of the degree of loading of the test conveyor.

Test results for selected types of belt tensioning devices are compiled on a graph (Fig. 11) showing their experimental static characteristics.

The characteristics on Fig. 11 show that for all tested tensioning systems the value of the tensioning force at the maximum values of the driving force is similar. However, with lower values of the driving force, the correct value of the tensioning force is ensured only by the proportional follow-up system and the operation of the other tensioning devices is characterized by a significant

excess tensioning force – TF (Fig. 11) in the belt compared to the required values.

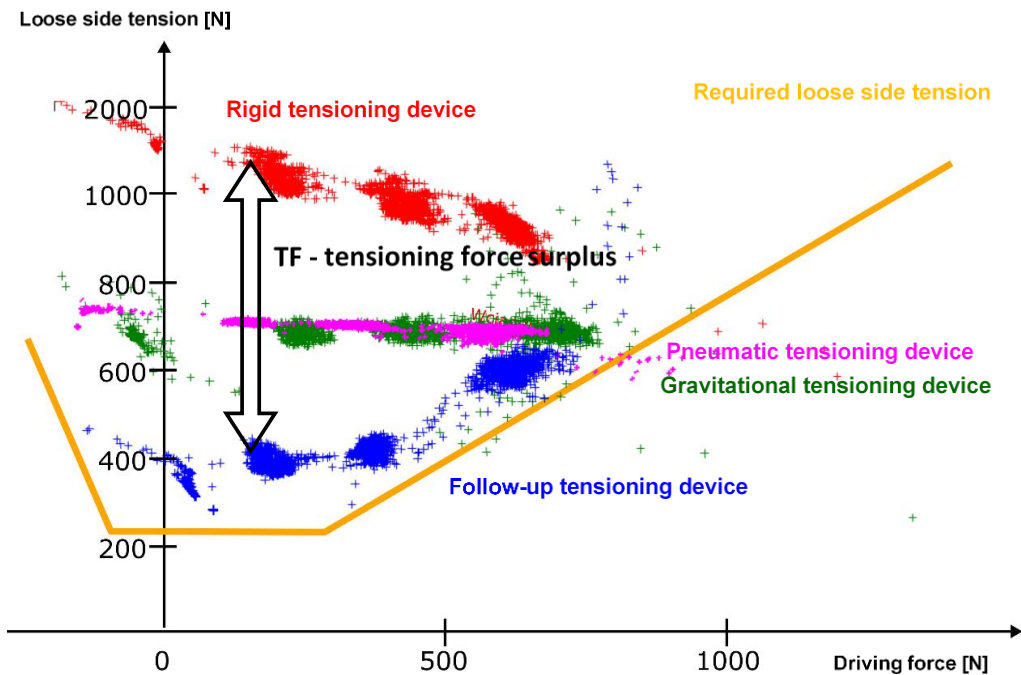


Fig. 11 Experimental static characteristics of rigid, gravitational, pneumatic and follow-up tensioning systems determined on the basis of laboratory belt conveyor measurements

Source: (Kasza and Kulinowski, 2014)

CONCLUSIONS

The results to date confirm the high versatility of the conveyor on which any type of belt tensioning device can be installed and tested under varying belt loading conditions. Measuring devices in conjunction with their proper configuration and using Labview software ensures high repeatability of test results. The most commonly used belt tensioning systems were tested, beginning from the simplest, rigid (winch) to gravitational, pneumatic and follow-up.

The research results authorize the following conclusions:

1. The use of main drive power to tighten the belt in conveyors with a follow-up tensioning device reduces the use of dynamic forces occurring in the belt during start-up, while ensuring its efficiency. They adjust the belt pre-tension forces continuously to the current needs of the conveyor, maintaining the values of these forces at the lowest possible level. This will reduce the stress in the belt, which can significantly increase the fatigue life of the belt core, its splices and drum assemblies.
2. Pneumatic and gravitational tensioning devices have similar tensioning characteristics, except that the pneumatic system has better features suppressing fluctuations in belt tension forces and greater ability to stabilize them, it is also possible to adjust the belt tensioning force depending on changing conveyor loading conditions. The pneumatic system, unlike the gravitational tensioning system, allows, after being equipped with

an automatic control system, a change in the tensioning force depending on changing operating conditions and loading conditions of the conveyor.

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Abstract.

The publication presents the evaluation of the effectiveness of belt tensioning systems based on the results of model laboratory tests. The types of tensioning devices most commonly used in industry were selected for testing: winch, gravity, pneumatic and follower. The evaluation of the efficiency of belt tensioning devices is complex, as the tensioning system is not autonomous and is only part of the belt conveyor equipment. Therefore, the publication presents the impact of belt tension force on the durability of basic conveyor components such as the belt and its joints, and drums. The characteristics of the tested belt tensioning devices are presented and the construction and research capabilities of the laboratory model of the belt conveyor are described. Measuring systems mounted on the conveyor are described in detail, enabling recording of variable conveyor operating conditions, measuring belt speed, driving force and belt stress. The results of the research are the experimental static characteristics of the most commonly used tensioning devices, which show the relationship between the drive moment and the belt tensioning force. Obtained characteristics will allow the development of guidelines for the design and selection of the most effective belt tensioning devices.

Keywords: conveyor belt, tensioning system, effectiveness