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Design and Implementation of a Dynamic Testing Rig for Testing of Pipe Conveyor Belts and their Components

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ABSTRACT

Pipe conveyors represent a continuous transport system that is difficult to obtain real operating data from in terms of operational characteristics' research. That is why the research of these conveyors is mainly supported with the data from special, static testing rigs. However, the measurements do not provide corresponding operating results and can differ from actual operating conditions. That is why, a dynamic testing rig was designed for the research which also represents the smallest pipe conveyor worldwide. The article describes options of conveyor belts and pipe belt conveyor components examination with the use of static and dynamic testing rig, and researches a new design and implementation of a dynamic testing rig - the smallest fully functional pipe belt conveyor in the world with a length of 11 m and belt width of 0.6 m. The said testing device can provide data obtained during dynamic operation of the pipe conveyor, which compared with a static rig increases the accuracy and value of obtained data and results.

Keywords: testing rig, pipe belt conveyor, conveyor belt.

INTRODUCTION

Development of continuous transport increases efficiency demands on transport performance to which reliability of transport equipment is related, too. In ecological transport systems, for the last 40 years, the pipe belt conveyors have been, worldwide, the most frequently used devices. The most important element of pipe belt conveyors is a specially constructed conveyor belt to which all the advantages of these conveyors can be attributed. This is the reason why conveyor belt manufacturers strive to develop newer and better designs. Nowadays, empirical knowledge is used in development without a deeper understanding of the issue [1-4]. Researchers are therefore moving towards using their own testing rigs. Current constructions of testing rigs with various designs enable performance of static or dynamic tests of the pipe conveyor belts resp. pipe conveyor components. Testing rig in Figure 1 was developed and constructed at Delft University of Technology in the Netherlands.

It consists of six boards arranged in a regular hexagon. Mounted on these boards are six plates that are in contact with a self-enclosed pipe conveyor belt. Twelve sensors are located between the boards and the plates, allowing to scan contact forces between the plates and self-enclosed steel cord belt of the pipe conveyor. The main disadvantage of this testing rig is that it was developed for only a certain width of a pipe conveyor belt.

Similar testing rig, but with a steel construction and adjustable diameters of the pipe conveyor belt in Figure 2, was developed by Xiaoxia et al. [6].

Testing rig to determine normal forces in steel cord belts of the conveyor belts was developed by PHOENIX Conveyor Belt Systems GmbH, in cooperation with the Institute of Transport and Automation Technologies (ITA) in Leibnitz, Germany, to examine normal forces in the conveyor belt under actual operating conditions (Figure 3). The

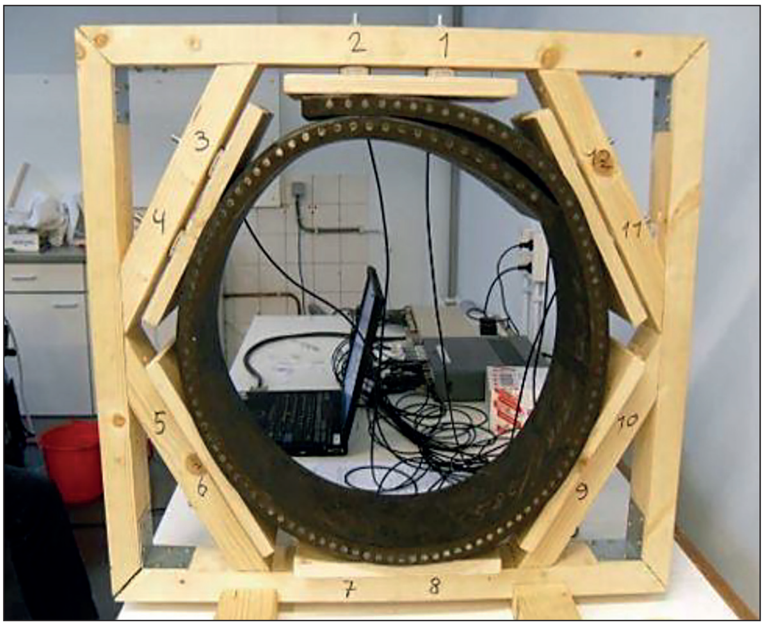

Figure 1. Six-plate wooden testing set-up at Delft University of Technology [5]

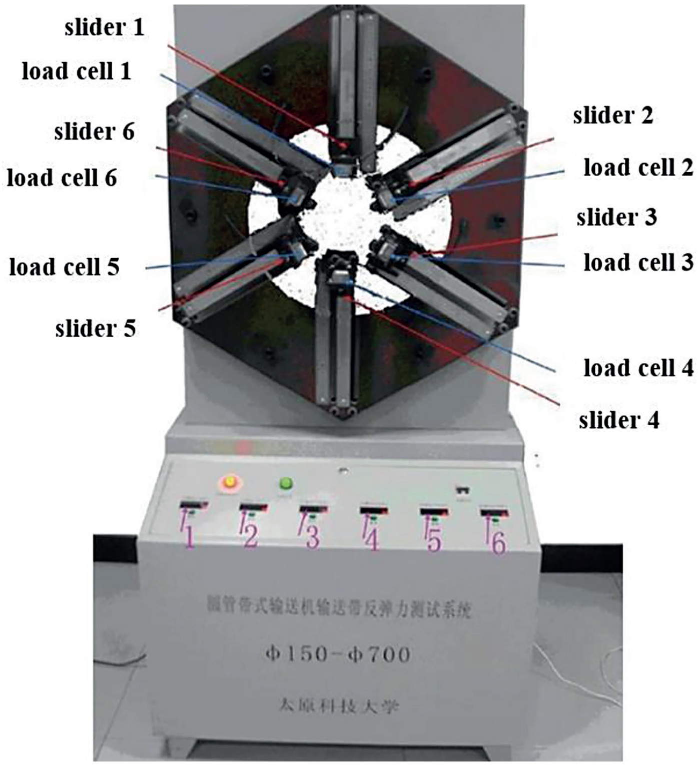

Figure 2. Six-point pipe belt stiffness testing rig of the Taiyuan University of Science and Technology [6]

diameter of enclosed conveyor belt, spacing of idler housings, arrangement of guide rollers, the radius of curvature and conveyor belt tensioning can all be set. The testing rig consists of a modular telescopic frame, so spacing of annular idler housings can be adjusted in a range of 1 m ÷ 2 m. The enclosed conveyor belt can pass through up to five idler housings, the position of which simulates the profile of the conveyor belt track on the testing rig.

A different testing rig for static tests of pipe conveyor belts (Figure 4) was developed by Michalik et al. [8, 10] at the Technical University in Košice, Slovak Republic. It consists of three frames representing idler housings of a pipe conveyor with an optional change of their distance.

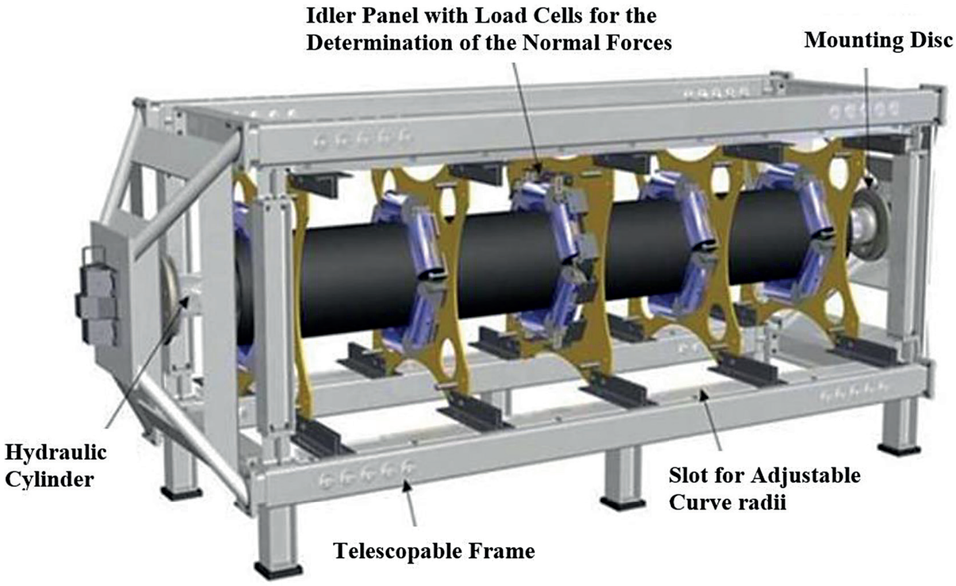

Figure 3. Testing rig for determination of normal forces in pipe belts [7]

Figure 4. Testing rig for static tests of conveyor belts at TU in Košice [8, 9]

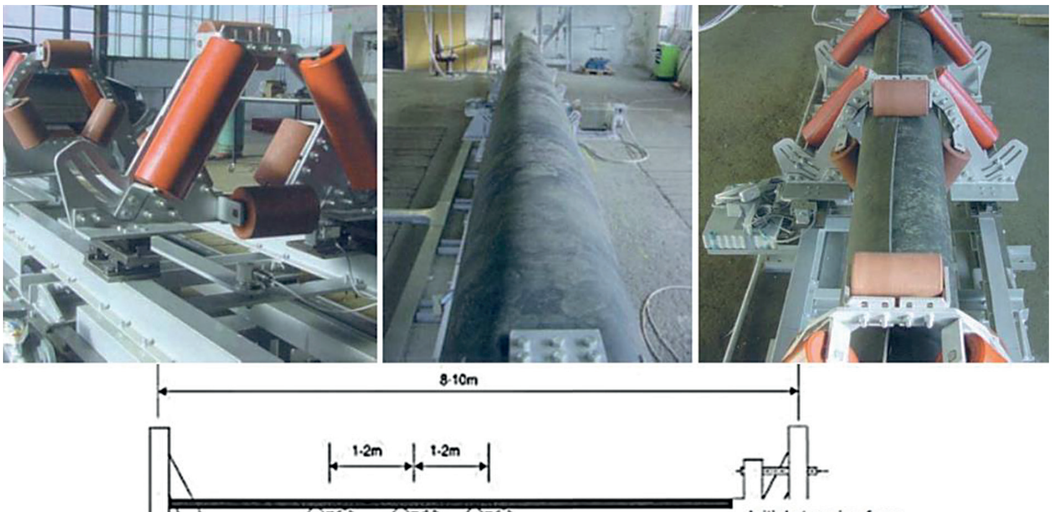

Figure 5. Dynamic testing rig at the University in Leoben [13]

On one side of these frames is a tensioning device for unenclosed belt and, on the other side is a tensioning device for the enclosed pipe conveyor belt. The testing rig designed this way enables many different measurements of pressure rollers and pipe conveyor belt's behavior to be carried out. Several modifications and technical improvements have been made to this testing rig [11, 12].

Dynamic tests were being performed on various dynamic testing rigs or by field measurements. One of them was designed and implemented by Hinterholzer et al. [13]. This testing rig was installed at the University of Leoben - Austria (Figure 5). Its principle is in a self-enclosed pipe conveyor belt, at rest, while idler housings with real rollers arranged in a regular hexagon are moving along it. The rollers contain rolling resistance sensors thus the contact forces were not being scanned on idler housings.

METHODOLOGY

The pipe conveyor transports material in a self-enclosed belt along entire transport route. Its pipe shape is maintained by six hexagonally arranged forming rollers in individual idler housings. At the point of filling and emptying, the belt opens into a classic trough shape. When transporting material in the bottom branch, the principle of the conveyor belt enclosing is the same, i.e., after tilting and filling, the conveyor belt self-encloses into a pipe shape and opens only in the emptying point as in Figure 6.

Pipe belt conveyors are used to transport various dry bulk and powder materials, such as cement, limestone, coal, iron ore, biomass, etc. They are widely used in cement industry, construction, mining, seaports, power plants and industrial plants. The individual branches can be positioned next to each other or above each other (Figure 7).

In general, it can be said that a pipe conveyor transports the amount of material equivalent to a conventional belt conveyor with three times the width compared to the pipe diameter. With the same capacities, the total width of a pipe conveyor in its central part, where the belt is enclosed, is 30 to 50% less than in a conventional belt conveyor. Pipe shape of the belt results in its small diameter dimension with a ratio of 2:1. Table 1 compares transport capacities of the pipe and conventional belt conveyors. Material transport

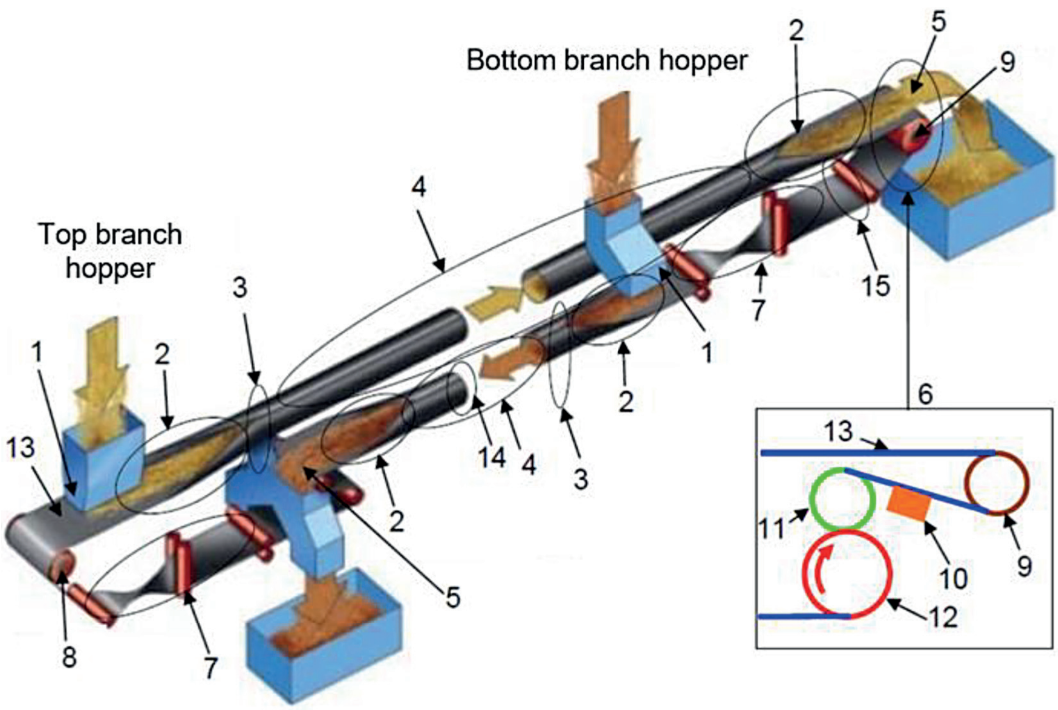

Figure 6. Layout of transport by a pipe conveyor in both branches [14]: 1 - hopper with impact rollers, 2 - trough idler housing with transition rollers, 3 - material flow monitor, 4 - annular idler housings with guide and adjusting rollers, 5 - emptying station, 6 - drive station, 7 - tilting unit, 8 - return drum, 9 - overflow drum, 10 - conveyor belt cleaner, 11 - guide drum, 12 - drive drum with a gearbox and an electric motor, 13 - conveyor belt, 14 - external circumferential conveyor belt cleaner, 15 - tensioning device

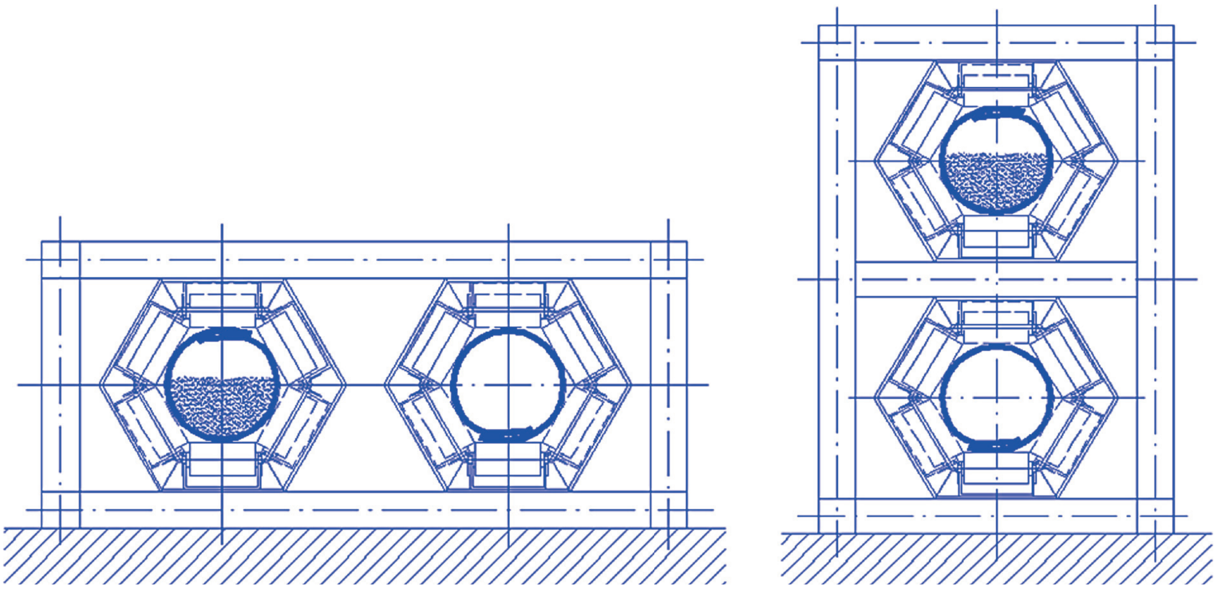

Figure 7. Pipe conveyor branches positioned side by side and above each other

speed v = 2.5 m.s^{-1}, material filling angle is 20° in a classic belt conveyor and the filling factor of a transport profile in the pipe conveyor is 0.75. Pipe conveyors will therefore logically not be suitable for applications requiring maximum transport performance, but rather the ones in which ecology, material and the environment protection need to be taken into account, and also, due to their construction, direct conveyors cannot be implemented [15].

The greatest advantage is reduction or elimination of transported material impact on the environment.

- can pass through vertically and horizontally rough terrain,
- the angle of inclination can be up to 30°,
- material transport is possible in both directions,
- transported material is protected from external influences,
- no extra power is needed as in conventional conveyors,
- compact construction without a need of refilling stations reduces noise levels and fits the environment.

Disadvantages of pipe conveyors in contrast with conventional belt conveyors are:

- greater additional belt strain when passing through the drum,
- higher investment costs compared to conventional belt conveyors,
- high price of the belt,
- many moving parts in idler housings making their installation and maintenance difficult.

External load changes the shape and dimensions of a rigid object. Mechanical properties express a change in shape, resp. dimensions of the object, triggered by external force. Mechanical properties include:

- elastic and deformation properties characterized by elasticity module, deformation module, etc.,
- stiffness properties such as compressive stiffness, tensile stiffness, skid stiffness, etc.

Conveyor belts' mechanical properties depend on their use and are therefore determined by mechanical tests. The required properties are determined by standards and/or technical/technological regulations. When performing mechanical tests and evaluating them, a fact that a conveyor belt consists of several types of materials needs to be considered. Mainly, rubber compounds from

Table 1. Transport capacities of a pipe and a conventional belt conveyor

Belt width [mm]	600	800	1000	1200	1600
Outer diameter of the pipe [mm]	165	215	270	325	400
Transport capacity – pipe conveyor [t.h^{-1}]	125	190	350	510	750
Transport capacity – belt conveyor [t.h^{-1}]	260	420	710	1130	1550

which cover and adhesive layers of the conveyor belt are formed, belong to a group of materials with more complex behavior when mechanically strained. Rubber properties largely depend on temperature and time, therefore a classic elasticity module, as in common construction materials such as concrete, steel, etc. [16], loses the meaning of a material constant, and becomes a material function depending mainly on temperature and length of strain. Therefore, mechanical tests are most often performed at normal room temperature (or in isothermal conditions). This eliminates temperature effect on the test course and its result. However, three variables remain, namely ε (elongation), σ (strain) and t (time). If one more variable is fixed, we limit ourselves to a pair of variables whose relationship is expressed in a usual way.

The main challenge for industries that use pipe conveyors is the lack of uniform standards that would help pipe conveyors and conveyor belts' design, thus guaranteeing reliable system operation in the field. Standards need to be developed that provide recommendations on a relationship between belt's main parameters, such as diameter, overlap percentage with respect to the belt width and a minimum lateral stiffness of the belt. Empirical experience combined with standards developed for conventional belt conveyors are usually being applied. Independent and confidential know-how of the companies operating in construction of pipelines and belts, common in normal competitive environment, leads to variations in products offered and their properties. To control quality of pipe conveyor belts, the properties of produced belts need to be experimentally determined. For this purpose, various testing rigs for pipe conveyors were built. Their task is to measure contact forces between the conveyor belt and the guide rollers [17]. If contact forces are too low or if there are contact losses between the belt and the guide rollers, the belt is not stiff enough and may not be able to remain enclosed. If contact forces are too high, the conveyor belt is too stiff and may use too much power while in operation. Depending on configuration of a testing rig, belt deflection can be measured along with belt tendency to deflect and twist in curves. As no uniform standard for a pipe conveyor testing rig exists, as well as no uniform testing procedures, differences in testing rig's design can affect experimental results and lead to incorrect conclusions on performance and reliability of tested products [18, 19, 20].

RESULTS AND DISCUSSION

BEUMER Group Czech Republic a.s. designed and manufactured for Technical University in Košice a testing rig for dynamic, static tests of conveyor belts and structural elements of pipe conveyors based on a real conveyor system – a pipe conveyor.

The device allows to examine:

1. magnitude of contact forces on selected rollers under various operating tensioning of the conveyor belt
2. conveyor belt life:
   - influence of shaping – lateral life, life of upper cover layer, life of edges,
   - influence of the glued joint – interlaced surfaces, contact of surfaces, interlaced surfaces with changed thickness of the cover layer,
   - influence of belting – lateral life, life of upper cover layer, life of edges,
3. motor power consumption after changes in pipe conveyor operating conditions: measuring of belt speed and tensioning drum speed
4. formation of longitudinal cracks in the conveyor belt under its different operating tensioning
5. rolling resistance in pipe conveyor belt at different operating tensioning of the conveyor belt

Within the research, when correctly or incorrectly mechanically shaping the conveyor belt, the following can be performed:

- accelerated tests of a conveyor belt lateral life at different operating tensioning,
- accelerated life tests of a belt upper covering layer (thermal stress),
- accelerated life tests of a conveyor belt edges (thermal stress),
- accelerated life tests of a conveyor belt overlapped surfaces at different operating tensioning,
- accelerated life tests of a conveyor belt contact surfaces at different operating tensioning,
- accelerated life tests of overlapped surfaces with a change in covering layer thickness at different operating tensioning.

Basic technical data of the proposed dynamic testing rig is in Table 2.

To compare results obtained from different testing rigs, a classic arrangement of dynamic testing rig construction was chosen - a straight section of empty pipe conveyor with the conveyor belt overlapping on the top and the bottom. A proposed testing rig is shown in Figure 8.

Table 2. Basic technical data of the proposed dynamic testing rig

Outer diameter of a pipe conveyor [mm]	150
Transport length [m]	12
Conveyor belt width [mm]	600
Transport speed [m.s^{-1}]	1.1
Transport length [m]	12
Transport height [m]	0
Installed power [kW]	7.5
Belt tensioning	with a screw
Number of fillings	1
Number of emptying(s)	1
Minimum radius [^{0}]	0
Total length [m]	13.429
Total width including a motor [m]	1.660
Total height [m]	1.426

Position 1 in Figure 8 is formed by a structure of a filling station with tensioning of the conveyor belt (Figure 9). Position 2 in Figure 8 is formed by a structure of an emptying station and a drive station with a conveyor belt drive (Figure 10). Both structures are designed as separate units - weldments of L and U steel profiles. They are connected to each other by screw joints allowing bends in horizontal or vertical direction, thus perfectly imitating operating conditions of pipe conveyors in industrial practice.

The filling and emptying stations have idler housings attached at various distances (Figure 11), with properly inclined forming rollers that ensure enclosing, enclosed shape and opening of the conveyor belt.

Figure 12 shows a testing rig for testing conveyor belts and pipe conveyor components with an installed conveyor belt.

Welded constructions (except idler housings - yellow finish) have a galvanized finish. The conveyor belt is driven by a three-phase electric motor with a frequency converter to control conveyor belt speed (Figure 13).

CONCLUSION

As already mentioned, research in the field of continuous transport systems is very demanding in terms of its implementation. It is often not possible to implement it in a sufficiently suitable way under real operating conditions. For this reason, the results of research presented so far are to some extent distorted and do not correspond

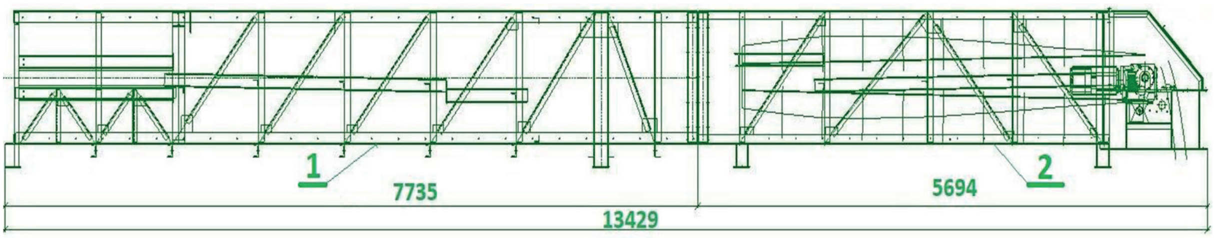

Figure 8. Proposed design of a testing rig

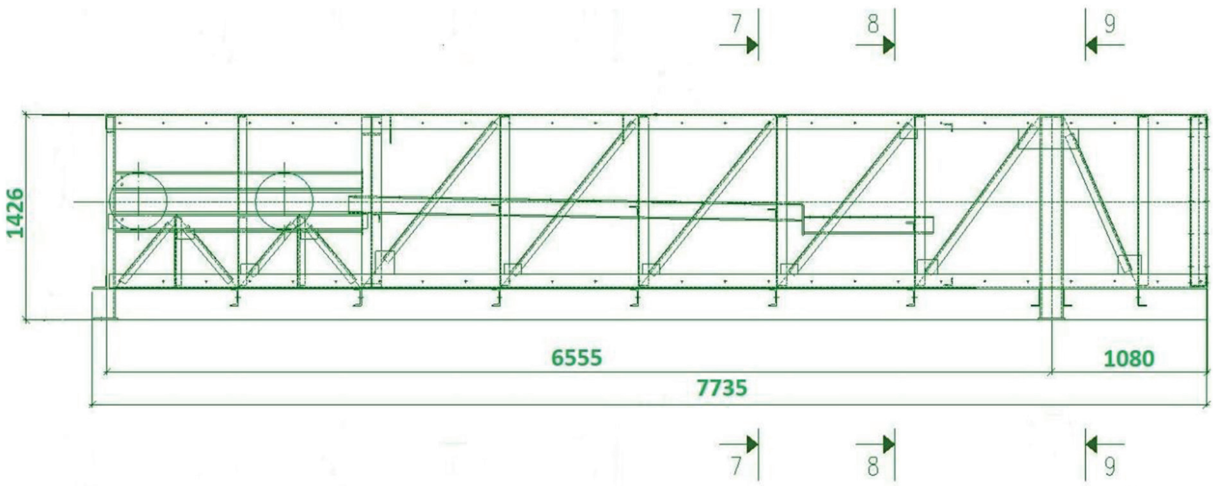

Figure 9. Filling station structure with tensioning of the conveyor belt

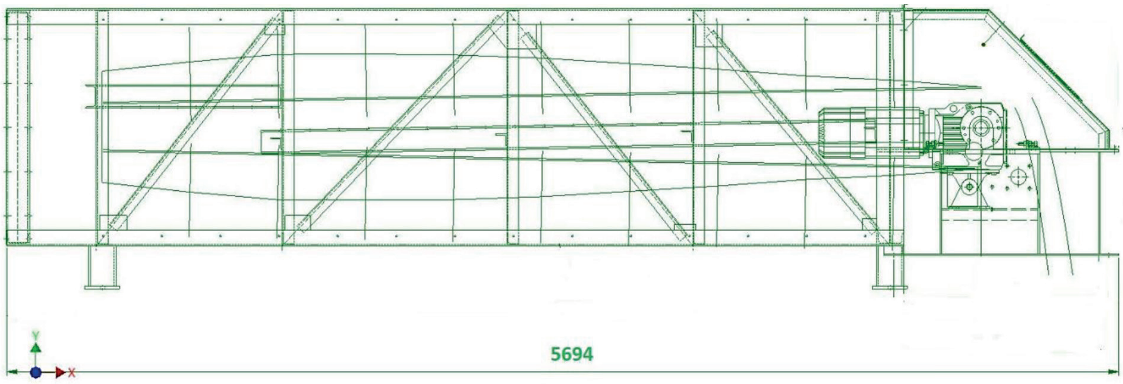

Figure 10. Emptying station and drive station structure

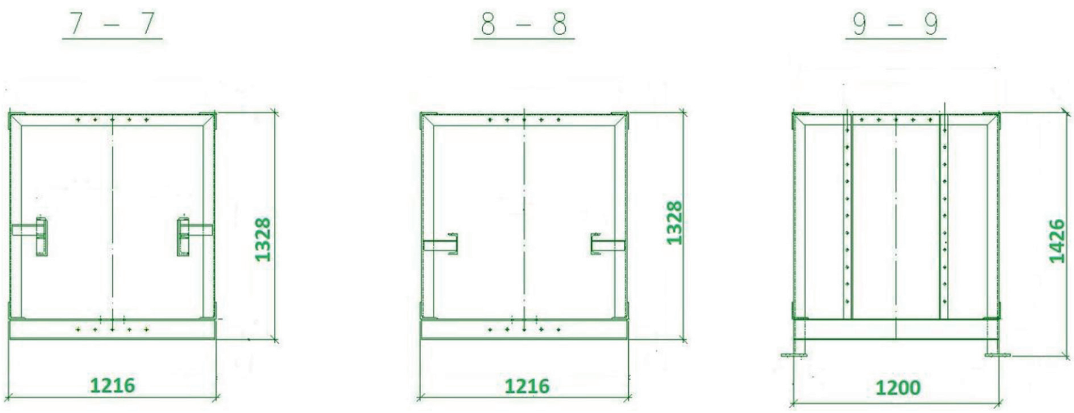

Figure 11. Idler housings in different sections of the testing rig

Figure 12. Testing rig for testing conveyor belts and pipe conveyor components

Figure 13. Emptying and drive station

completely to reality. Nevertheless, the results published so far obtained thanks to static testing rig have their value.

In addition to all advantages (low cost, easy, mobile, possible instant replacement of a conveyor belt sample), the static testing rig of pipe conveyor belts also has several disadvantages. One of them is contact forces measurement and testing of belt stiffness without a possibility to simulate real operation. In addition, most of them are designed only for straight sections of pipe conveyors routes and are not suitable for examining conveyor belt operation in curves, as well as under various belt tensioning, resp. in real transport of bulk material.

However, further research in the field must be more precise and must provide real operational data. At the same time, it is necessary to focus on research implementation in real operating conditions. For this purpose, a dynamic testing rig was developed, which eliminates the shortcomings and limitations of static testing rigs.

Dynamic Testing Rig eliminates these shortcomings and, with its proposed parameters and properties, brings an opportunity to obtain new experimental results from the operation of conveyor belts and their components, which will help clarify until now only empirical knowledge without deeper understanding, and improve new pipe conveyors constructions.

Dynamic testing rig will enable to carry out research in real operating conditions. Obtained results will be only be minimally distorted and will serve as the basis for comprehension of transport system's operating parameters.

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