Test of the retractable guidance system installed on the level 960 m in the Leon IV shaft in Rydułtowy Coal Mine, Poland

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Abstract. Rope guidance of the conveyances is a reliable and convenient way of guiding cages and skips in the mine shafts and it is used in numerous underground mines all over the world. However it is not popular in Polish coal mines. Most of the Polish copper and coal mines operate on multiple levels, which requires mine shafts and hoists to support more than one level. In such situation it is necessary to install some kind of chairing system on the levels, i.e. stiff guides in their vicinity. Conveyance’s movement through the stiff guides on the level requires its speed reduction, which in turn leads to lowering of the hoist’s effectiveness. To avoid such situation, retractable guidance system was introduced on the level 960 in the Leon IV shaft in Rydułtowy Coal Mine, Poland. This paper presents the idea of the retractable guidance system, as well as calculations and measurements carried out to prove that the system is safe and reliable.

1. Introduction
Rope guidance of conveyances is in popular use in numerous mine shafts in different underground mines all over the world. Besides its disadvantages, it does have multiple advantages, associated with its installation and operation, as well as economic benefits. Installation of elastic guidance is much quicker and cheaper than the assembly of stiff guides, similar to its maintenance and potential replacement. Rope guidance allows conveyances to travel with high speed, because of the smooth guidance, without shocks and collisions with the guides [1-3].

However, elastic guidance does have an essential disadvantage, which is a necessity for installation of the stiff guidance on the levels. It is crucial to ensure safety of the operation of the hoist. It is also required by Polish law. Because of this requirement, elastic guidance of the conveyances is rarely used in Polish coal mines and in common use in Polish copper mines. It is caused by multilevel exploitation, which enforces one mine shaft with its hoist to operate on many levels, which in turns requires installation of the stiff guidance on each of these levels [4-6].

The biggest inconvenience of the stiff guidance on the levels is the process of the conveyance’s entry onto the guides, because of the conveyance’s lateral movements, intensified by conveyance’s braking and turbulent air flow in the vicinity of the level. Necessity for conveyance’s speed reduction decreases level of effectiveness of the mine shaft and a hoist [7-10].
For purpose of improvement of elastic guidance operation and raise of effectiveness level of the mine shaft and the hoist, retractable guidance system was introduced on the level 960 m in the Leon IV shaft in the Rydultowy Coal Mine (currently ROW Colliery, Rydultowy department). Patented retractable guidance system allows the conveyance to travel through the mine level with its full operational speed, if people or materials are transferred to a different mine level or in case of transport to the level 960 m, provides conveyance’s stability on that level [11].

The problem with stiff guidance on the mine levels, described above, was neither examined nor solved, because the rope guidance of conveyances is rather rarely used in Polish coal mines, mostly because of its disadvantages listed above. Presented solution is innovative because it utilizes hydraulic cylinder to stabilize the conveyance in very safe manner. Additionally, any major intervention in the conveyance’s construction is not required, as it was in similar historic constructions. The construction of the retractable guidance system and the mine level allows installation of swinging bridges, which is important to provide safe and reliable transport of materials to the level 960 m [12-15].

Described solution is a pioneering approach in Polish mining industry. It has helped to raise a level of effectiveness of the Leon IV shaft in the ROW Colliery, Rydultowy department, where it was used. It might also help to raise safety and effectiveness level in other mine shafts in different Polish underground mines.

2. Design of the retractable guidance system

Retractable guidance system replaced the chairing mechanism of a rope guided cage at level 960 of Leon IV shaft in the Rydultowy Coal Mine. This system was originally introduced in the project [16] and it was developed to solve the problem of the cage guidance through the level 960. The main reason for development of this system was to reconcile safety with effectiveness. To provide proper level of safety using chairing system it was necessary to reduce speed of the cage from 10 m/s to 0,5 m/s, 100 m before the level 960. The effect of such situation was significant as regards an extension of a single ride time to or from the level 1150 m.

Stiff guides on the level 960 m were replaced with the retractable guidance system, which consist of two pairs of top and two pairs of bottom guides and a supporting structure, comprising of four supporting frames assembled to the shaft lining by additional beams, structurally independent from the existing shaft chairing [17-18].

Retractable guides can be moved between two positions: resting and working ones. The motion is restricted by:

- the element of the supporting frame, named the race – bottom section;
- two articulated links (top and bottom) – top section.

Each of the bottom sections of the retractable guidance system are driven by hydraulic cylinder, assembled to the guide’s section and the supporting frame. Top sections of the retractable guidance system are driven by two hydraulic cylinders each.

During the movement of the conveyance between the levels 1150 and zero, all sections of the retractable guidance system are set in resting position (Figure 1).
Retractable guidance system set in resting position allows the conveyance to move through the level 960 with its full speed, which is equal 10 m/s. The system is also set in the resting mode when the cage is moves between levels 960 and 1150 in both directions.

The system is set in the working mode when the cage stops at the level 960. It is done by a banksman on the level 960. Sections of the retractable guidance system in the working position stabilizes the conveyance on the level. Sections of the system are inserted between the elements of the guiding shoes of the cage. Sections of the retractable guidance system in working position are presented in Figure 2 [11, 16].

**Figure 1.** Sections of the retractable guidance system in resting position.
1 – supporting frame of the bottom section, 2, 4 – rope guides, 3 – bottom transom of the cage, 5 – top transom, 6 – supporting frame of the top section, 7 – top section of the retractable guidance system

**Figure 2.** Sections of the retractable guidance system in working position.
1 – bottom section of the retractable guidance system, 2 – guiding shoe, 3 – bottom transom, 4 – top transom, 5 – guiding shoe, 6 – top section of the retractable guidance system
Layout of the retractable guidance system is shown in Figure 3. The sections of the system comprise of 180 x 260 mm box beams made of C260 profiles. Supporting frames, made of HEB 260 are attached to two technological beams with M24 Hex bolts, class 8.8.

Figure 3. Layout of the adjustable guiding (shown in grey colour).

Static analysis was performed for the constructions. Assumptions, schemes and results are presented below:

STATIC ANALYSIS – BOTTOM SECTION

Input data:

- Transportation unit load: 200 kN
- Continuous load:
  \[ q = \frac{200 \text{kN}}{1.654 \text{m}} = 120.92 \text{ kN/m} \]
  Rounded value of the load is equal 121 kN/m
- Factor of safety
  \[ \frac{480}{62.87} = 7.63 \]
- Force caused by hydraulic cylinder: 139.2 kN
**Figure 4.** Static analysis of the bottom section:
- a) bottom section layout, b) loading scheme of the bottom section, c) model, nodes and constraints, d) loading scheme of the bottom section, e) stress in the bottom section.

**STATIC ANALYSIS – TOP SECTION**

Input data:
- Transportation unit load: 200 kN
- Continuous load:
  \[ q = \frac{200\text{kN}}{1.654\text{m}} = 120.92 \frac{\text{kN}}{\text{m}} \]
  Rounded value of the load is equal 121 kN/m
- Factor of safety
  \[ \frac{480}{75.09} = 6.392 \]
- Force caused by hydraulic cylinder: 139.2 kN

**Figure 5.** Static analysis of the top section:
- a) model of the top section, b) loading scheme, c) deformation of the top section, d) stress in top section elements.
3. Measurements

3.1. Measurements of stiff guides

Presented measurements were conducted to determine peak forces acting on the stiff guides on the level 960 m in the Leon IV shaft, caused by the man-material cage. Results were obtained by measuring value of peak frontal and side forces acting on each of eight stiff guides, four of them cooperating with the top transom and another four with the bottom transom of the cage, during movement of a platform with the total load of 20 tons through a bottom level of the conveyance.

Because of the technical issues, tests were conducted in two stages. First part, consisting of twelve experimental cycles of pushing the platform through the cage, was conducted on the level 960 m of the Leon IV shaft. Another part was performed out of the shaft after the finish of the first stage.

The essence of the first test stage was generation and record of specific measurement signals using specialized instrumentation. The signal represents from mathematical point of view the forces that were to measure. Second stage of the test covered processing of gathered data by computer to obtain measured forces. Method of such processing were presented in several publications, e.g. [19]. Desirable results are obtained using specialized instrumentation, which was previously used in numerous tests in mine shafts. This device allows to achieve uncertainty of measurement of the range of 12 percent.

A special clamping system was designed to attach measuring device to the top and the bottom transom of the man-material cage in the Leon IV shaft. The clamping system allowed the first stage of test to be conducted in the shaft in two phases:

- phase one, conducted to measure forces on the bottom transom of the man-material cage, consists of six experimental cycles of moving the platform through the bottom level of the conveyance,
- phase two, conducted to measure forces on the top transom of the man-material cage, consists of six experimental cycles of moving the platform through the bottom level of the conveyance.

Figures 6 and 7 present diagrams of measured forces. Diagrams presented on the Figure 6 presents forces measured on the bottom transom of the man-material cage, while schemes shown in the Figure 7 presents forces measured on the top transom of the conveyance.

Figure 6. Diagram of the forces on the bottom transom of the man-material cage.
Figure 7. Diagrams of the forces acting on the top transom of the man-material cage.

Markings of measured forces, presented in the figures above, consists of:

- numeric prefix 1, 2, 3 or 4, which match first, second, third or fourth phase of the platform movement through the bottom level of the cage, where:
  - phase 1 comprises of the entrance of the front wheels of the platform onto the cage bottom level,
  - phase 2 comprises of stabilizing the platform in the conveyance,
  - phase 3 comprises of the exit of the front wheels of the platform from the conveyance,
  - phase 4 comprises of the exit of the rear wheels of the platform from the cage.
- letter P in each of the marking in the figures 6. and 7. informs that the force was measured on the bottom transom (from Polish pomost), while letter G – on the top transom (glowica).
- letter N informs if the force acted on the guide located on the north, while letter S – on the south.
- letter Z informs that the force acted on the guide located on the side of the entry of the platform into the cage (zapychanie), while letter W – on the side of the exit from the conveyance (wyjazd).
- letter C in each marking corresponds to the frontal forces (czolowa) and letter B to the side forces (boczna).

Tables 1. and 2. present selected peak forces of measured forces, eight for each stiff guide cooperating with the top and bottom transom. Frontal forces are shown in the table 1 and side forces – in the table 2.

Table 1. Peak frontal forces caused by the man-material cage acting on the stiff guidance.

| Force marking | 1. phase | 2. phase | 3. phase | 4. phase |
|---------------|----------|----------|----------|----------|
|               | Bottom transom | Top transom | Bottom transom | Top transom | Bottom transom | Top transom | Bottom transom | Top transom |
| NWC           | 42.3      | 28.4      | 29.7      | 22.1      | 48.3      | 20.0      | 36.8      | 44.3      |
| NZC           | 35.9      | 21.6      | 32.5      | 23.8      | 35.8      | 31.4      | 27.2      | 25.9      |
| SWC           | 32.8      | 29.1      | 28.5      | 23.0      | 36.2      | 30.3      | 30.3      | 48.2      |
| SZC           | 36.6      | 36.7      | 29.5      | 19.8      | 31.3      | 25.4      | 40.1      | 24.0      |
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Table 2. Peak side forces caused by the man-material cage acting on the stiff guidance.

| Force marking | 1. phase Bottom transom | 1. phase Top transom | 2. phase Bottom transom | 2. phase Top transom | 3. phase Bottom transom | 3. phase Top transom | 4. phase Bottom transom | 4. phase Top transom |
|---------------|-------------------------|---------------------|-------------------------|---------------------|-------------------------|---------------------|-------------------------|---------------------|
| NWB           | 14.1                    | 5.5                 | 5.9                     | 5.1                 | 13.1                    | 7.4                 | 20.1                    | 11.5                |
| NZB           | 15.4                    | 12.5                | 7.6                     | 3.3                 | 8.9                     | 6.1                 | 8.9                     | 8.0                 |
| SWB           | 16.5                    | 7.5                 | 6.4                     | 3.7                 | 16.7                    | 6.2                 | 17.8                    | 18.4                |
| SZB           | 19.8                    | 9.5                 | 5.8                     | 7.5                 | 17.3                    | 6.7                 | 11.8                    | 7.3                 |

On the basis of tests results presented above, following conclusions were formulated:

1. Values of frontal forces acting on the stiff guidance on the level 960 m and caused by the man-material cage during loading and unloading its bottom level are diverse, because of clearances between guides and the cage as well as random dynamic of:
   a) entry of the platform’s front and rear wheels into the cage’s level,
   b) exit of the platform’s front and rear wheels from the conveyance’s level.

Dynamic’s randomness was recognized the main reason of the occurrence of the peak frontal force equal 42.3 kN during loading and 48.3 kN during unloading of the conveyance.

2. Results obtained suggest that peak frontal forces acting on the stiff guides and caused by cage’s guide shoe on the top transom should be considered equal to peak forces caused by the guide shoe located near the bottom transom of the cage.

3. Measured peak side forces did not exceed level of 42 percent of peak frontal forces. It should be taken into account that the biggest values of side forces occur in the case of derailing of the platform during its movement through the conveyance, which not happened during the test.

3.2. Measurements of retractable guidance system

Following test aimed in determining peak forces acting on the retractable guidance system on the level 960 m in the Leon IV shaft during loading and unloading of the man-material cage.

Because of the technical conditions, test was parted in two stages. First of them was conducted in the Leon IV shaft and it comprised of generation and record of measuring signals in twelve experimental cycles of moving the platform with the load of 20 tons through the bottom level of the man-material cage. Measuring signals are in a relationship with measured forces and stress. Second stage was carried out after the finish of the first part and it consists of processing of obtained signals. It resulted in values of forces and stress and graphs of their distribution.

Presented tests were conducted similarly to previous measurements, conducted for the case of stiff guidance on the level 960 m and presented in previous section. Retractable guidance system stabilizes the conveyance on the level of its top and bottom transom, it does not provide additional stabilization in the middle of the cage (on the floor of second cage level). Such feature was not considered necessary.

The extension of test was realized by utilization of two additional measuring units, located on the floor of the second cage level, together with the basic measuring units, described in the previous section. All of the measuring units are synchronized, thus the uncertainty of measurement is the same as it was in the previous case, so less than 12 percent.

Schedule of the test was similar to the one conducted for stiff guides, presented in previous section. It was divided into two parts”

- stage “Bottom transom”, consisting of two series, including three experimental cycles of moving the platform with load of 20 tons through the bottom level of the cage each. During the first part, measuring unit was located on the bottom transom of the conveyance;
- stage “Top transom”, consisting of two series, including three experimental cycles of moving the platform with load of 20 tons through the bottom level of the cage each. During the second part, measuring unit was located on the top transom of the conveyance.
In both stages of the experiment, additional measuring units, located on the middle beam of the cage (floor of the second cage level), were used.

4. Comparative analysis of forces measured for stiff guides and for the retractable guidance system on the level 960 m in the Leon IV shaft

For the purpose of the analysis, peak values of compared forces are listed in tables 3 and 4.

| Marking of the force | Peak frontal forces caused by the bottom transom of the man-material cage acting on the guides | Peak frontal forces caused by the top transom of the man-material cage acting on the guides |
|---------------------|-------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|
| NWC                 | 38.9 kN                                                                                           | 39.7 kN                                                                                 |
| NZC                 | 40.8 kN                                                                                           | 34.9 kN                                                                                 |
| SWC                 | 40.7 kN                                                                                           | 40.2 kN                                                                                 |
| SZC                 | 38.3 kN                                                                                           | 36.3 kN                                                                                 |

| Marking of the force | Peak side forces caused by the bottom transom of the man-material cage acting on the guides | Peak side forces caused by the top transom of the man-material cage acting on the guides |
|---------------------|-------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|
| NWC                 | 17.2 kN                                                                                           | 11.0 kN                                                                                 |
| NZB                 | 15.0 kN                                                                                           | 12.2 kN                                                                                 |
| SWB                 | 17.1 kN                                                                                           | 15.2 kN                                                                                 |
| SZB                 | 17.9 kN                                                                                           | 14.1 kN                                                                                 |

Table 3 shows that peak frontal forces caused by the bottom transom of the man-material cage and acting on the retractable guides were equal 40.8 kN and on the stiff guides 48.3 kN, respectively forces caused by the top transom for the retractable guides were equal 40.2 kN and for the stiff guides 48.2 kN.

Respectively table 4. shows that peak side forces caused by the bottom transom and acting on the retractable guides were equal 17.9 kN, whereas side forces acting on the stiff guidance were equal 20.1 kN. Top transom caused forces equal 15.2 kN, acting on the retractable guides and 18.4 kN on the stiff guides.

Basing on the presented analysis of the measured forces, one can conclude that values of both peak frontal and side forces caused by bottom and top transom of the man-material cage acting on the construction of the retractable guidance system are significantly lower than the forces acting on the stiff guidance used on the level 960 m in the Leon IV shaft. Such reduction of obtained forces’ values may be a result of lower value of the clearance between the retractable guide and the conveyance that between the cage and the stiff guides [20].

5. Comparison of forces measured for the retractable guidance system and valid legislation in terms of safety and Polish Standard PN-G-46227. Mine shafts: Chairing. Requirements.

5.1. Design forces for the retractable guidance system according to Standard

Polish standard PN-G-46227. Mine shafts: Chairing. Requirements [21] does not include definition of the term “retractable guidance system”, but because of the analogy between functions of chairing system (defined in the Polish Standard) and retractable guidance system, requirements for chairing system should be considered during measurements and evaluation of the retractable guidance system construction.
Standard [21] consist of following requirements for design forces acting on shaft chairing construction (2.1.1.3):

“Horizontal load acting on the shaft chairing construction during loading a cage with mine cart should be taken equal to peak force acting on a tub creeper’s driver, but not less than 10 kN.”

“Load-bearing elements of the shaft chairing should be characterized with at least six times high safety factor, without taking wear limit into account.”

Cited paragraphs should be considered sufficient for purpose of determination of the design forces of the shaft chairing construction, but only if the system has a typical form of construction. However, construction of the retractable guidance system can be considered shaft chairing system only in terms of its functions, thus determination of design forces according to requirements of the Standard [21] involves additional assumptions for both tub creeper driver’s load distribution on different elements of retractable guidance system and selection of design side force acting on these elements.

An attempt to prove the existence of mentioned load distribution was made by comparing peak frontal forces acting on retractable guides and caused by tub creeper – determined as 20 kN [22] with measured peak forces (table 3.). However, this load distribution’s existence was not clearly proven. It suggests that peak force caused by tub creeper should be assumed equal to peak design force acting on each of eight retractable guides installed on the level 960 m in the Leon IV shaft.

In terms of side forces acting on the retractable guidance system’s elements, it should be assumed, that their construction, different than typical shaft chairing’s construction, precludes a priori assumption of compliance of the strength requirements of the side forces, basing on previously presented their compliance in case of the frontal forces. Analysis of side forces revealed that the greatest value of side force acting on the retractable guides occurs in the case of derailment of the transport unit, which had not happened during tests. However, peak side force value in case of the derailment can be estimated basing on the measurement’s results. According to this estimation, peak side force value is about 70% higher than measured peak side force and peak frontal force is about 30% lower than measured peak frontal force.

According to facts and assumptions presented above, it was considered reasonable to include two cases during calculation of the forces acting on the retractable guidance system:

• case 1., consisting of design force calculated according to the Standard [21], as the peak force acting on the tub creeper’s driver. However, calculations are conducted for case of this force acting on each of the retractable guides,

• case 2., comprising of the transport unit’s derailments, with simultaneously acting peak frontal and side forces, equal respectively 70% of peak force on the tub creeper’s driver, acting on each of the retractable guides.

5.2. Evaluation of measured forces acting on the retractable guidance system

The base of the evaluation presented below are the safety factor specified in the Standard [21] for the shaft chairing’s construction and in the appendix 4. to Regulation [23], in which shaft chairing is considered “auxiliary equipment of the mine shaft”.

Required safety factor, presented both in the Standard [21] and Regulation [23] is characterized with equal value, but section 3.15. of the appendix 4. to the Regulation [23] makes this factor a criterion for design stress verification, specifying:

• definition of load-bearing elements’ safety factor calculation, as the ratio of the tensile strength $R_m$ of the material and the design stress,

• legitimacy of the Standard’s [21] record, which states that wear limit of shaft chairing’s elements is not included in their design stresses,

• requirement for corrosion and wear allowance for steel elements of shaft chairing’s construction.

Basing on the Standard [21] and requirements of the Regulation [23] obligatory safety factor for load-bearing elements of the shaft chairing was defined as a product of three coefficients:

• $n_d$ – coefficient of frontal dynamic loads acting on the shaft chairing construction.
• $n_d$ – coefficient of limit stress of load-bearing elements of the shaft chairing,
• $n_g$ – coefficient of wear limit of shaft chairing elements.

Coefficient $n_d$ is defined as a ratio of peak frontal force acting on the retractable guides (table 3.) and peak force measured on the tub creeper’s driver [22], which is the cause of the force acting on the guides. Calculated value of the $n_d$ coefficient is equal 2.0.

Coefficient $n_g$ was defined because limit stress in the retractable guides is equal to the yield point of the material of which they are made, but verification of stress in the guides should be done basing on its tensile strength, according to the Regulation [23]. Thus, the value of coefficient $n_g$ was accepted at the level of 1.8.

Finally, the coefficient $n_z$ is calculated as a ratio of required safety factor and product of coefficients $n_d$ and $n_g$. According to this, value of the coefficient $n_z$ is equal 1.67.

Based on values of the coefficients presented above, following note of the forces measured on the retractable guidance system was formulated:

- Peak frontal forces acting on the retractable guidance system, treated as shaft chairing (basing on the existing Regulation [23] and Standard [21]), measured in tests can be considered safe (according to the Regulation [23]), if each of the load-bearing elements of its construction is characterized with safety factor not less than 6 for the peak force caused by the tub creeper’s driver acting on each of the eight retractable guides installed on the level 960 m in the Leon IV shaft.

- Peak side forces acting on the retractable guidance system, treated as shaft chairing, measured in tests can be considered safe (according to the Regulation [23]), if each of the load-bearing elements of its construction is characterized with safety factor not less than 6 for the simultaneously acting peak frontal and side forces, equal respectively 70% of peak force on the tub creeper’s driver, acting on each of the retractable guides.

- Basing on the calculated safety factors presented above, corrosion and wear allowance (according to the section 3.15.1 of the appendix 4. to the Regulation [23]) can be determined for sections used as the load-bearing elements of the retractable guidance system’s construction. To calculate this allowance, following formula is recommended to use:

$$\Delta = 1.83 \times n_{\text{min}}^2 - 5.14 \times n_{\text{min}} - 5.18$$

(5.1)

where:

$\Delta$ – limit of wear, as a part of initial section wall thickness, [%],

$n_{\text{min}}$ – the smallest safety factor calculated for load-bearing elements of the retractable guidance system’s construction.

6. Conclusions

Physical verification of quantities measured in presented tests, which are value of peak frontal forces acting on the stiff and retractable guides revealed that measured forces are satisfactorily reliable image of real forces acting on the elements of the retractable guidance system and the cage in the process of loading and unloading of the cage on the level 960 m in the Leon IV shaft with the transport units of the maximum load possible for the conveyance.

Presented tests demonstrate that:

- peak frontal forces acting on the elements of the retractable guidance system, treated as auxiliary shaft equipment [23] can be considered safe, according to the existing law, if value of design safety factor is not less than six, for the maximum possible force caused by the tub creeper’s driver acting on each of the load-bearing elements of the retractable guidance system on the level 960 m in the Leon IV shaft,
- peak side forces acting on the retractable guidance system, treated as shaft chairing, measured in tests can be considered safe (according to the Regulation [23]), if each of the load-bearing elements of its construction is characterized with safety factor not less than 6 for the
simultaneously acting peak frontal and side forces, equal respectively 70% of peak force on
the tub creeper’s driver, acting on each of the retractable guides.

- Basing on the calculated safety factors presented above, corrosion and wear allowance
  (according to the section 3.15.1 of the appendix 4. to the Regulation [23]) can be determined
  for sections used as the load-bearing elements of the retractable guidance system’s
  construction. To calculate this allowance, introduced in the Standard [20] and presented in this
  work, formula (5.1) is recommended to use.

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