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Rescue drive for the gondola cableway system. Example of the Solina cableway

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Abstract: Rescue drives applied in continuous traffic cable railways have not been a standard solution. The main reason for this is the ability to ensure effective evacuation of passengers by traditional methods, i.e., rescue teams and methods known as evacuation from heights. This is mainly a result of the usually convenient location of the on-site cableway system and easy access to the vehicles (cars) from the ground level and the overhead driving cable or route pylons. In the case of the Solina gondola cableway, access to vehicles (cars) in the manner mentioned above at the prevailing section of the route is impossible or extremely difficult and even dangerous. Hence, the passenger evacuation concept utilizing the rescue drive in case of damage to the main and emergency drives of the cableway in question has become indispensable and necessary [19].
Keywords: safety, risk in gondola cableway system, rescue drives, a passenger evacuation concept.

1. Preface

The oldest records and drawings depicting the use of ropeways come from Europe and China (15th century). The primary and most responsible element of the ropeway is the rope [9] [11], [15], [16]. The first ropeways used ropes twisted from plant fibers (sisal and hemp). These railways were used to transport both people and goods. The breakthrough was the invention in 1834 of ropes braided from steel wires. The first modern cableway for transporting people was built in 1866 in Schaffhausen, Switzerland. The first passenger cableway in Poland (then under partition) was made in Lviv and operated from July 2 to October 15, 1894, at the National Exhibition, during which the economic and cultural achievements of Galicia, as well as Polish works of art and culture, were displayed.

In the Second Polish Republic, ropeways' development did not occur until the mid-1930s. At that time, the ropeway to Kasprowy Wierch (1936), the funicular to Góra Parkowa in

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Krynica (1937), the funicular to Gubałówka (1938), and two sleigh lifts were built in Kocioł Gąsienicowy and Sławsk in the Stanisławów, in the Stryj county.

For the device to be generally recognized as a cableway installation, according to EU regulations, it should meet both of the following conditions:

- Condition I. At least one rope of such an installation must be movable.
- Condition II. The installation must be intended solely for transporting persons (exceptionally for transporting persons and a small load simultaneously). It must not be used for recreational or sporting purposes [1], [2].

Passengers ropeways can now be divided as follows [7], [8], [10], [11]:

a) shuttle cable railways,
b) circular cable railways, including continuous traffic cable railways; pulsation traffic cable railways; gondola cable railways; open gondola cable railways; chair cable railways; single-cable railways; single-cable railways with a doubled cable; double-cable railways; cable-ground railways.

It is worth pointing out that load transportation cable railways (for goods only) are excluded from EU regulation [1], [11].

Evacuation of passengers must be possible if installations malfunction for any reason. In such cases, passengers must be evacuated and moved to a safe, sheltered place, preferably to the lower terminal of a ropeway where public transport facilities are available [10]. There are now several well-known evacuation concepts [10]: roping down passengers, applicable on most aerial ropeways; evacuation by helicopter; winch-propelled rescue car, mainly applicable for systems with track ropes; rescue tram with spliced rescue rope to a loop; towing of main cars on circulating systems; rescue carrier for monocable circulating systems; self-propelled rescue carriers; integrated rescue; various rescue systems; stairs on funiculars.

For obvious reasons, we will not discuss every concept of evacuation here. While considering the method mentioned above in point h), one can say that most recently, the "integrated rescue" method was also introduced for tricable ropeways and monocable circulating ropeways. The integrated rescue system consists of backup equipment in case of any equipment failure in moving the haul rope.

In the case presented here (monocable circulating ropeways), provisions are made for quickly lifting a derailed, fully loaded rope back on the roller battery. Additionally, supervision of rope position is essential.

The evacuation concept developed by Doppelmayr Seilbahnen GmbH, in the event of a major failure of the cableway drives, ensures that passengers can be transported to the nearest station without the need for a separate and additional device designed exclusively for evacuation or other means designed for evacuation by mountaineering techniques from height. The new passenger evacuation concept involves "bringing vehicles" to final stations. The concept has successfully passed safety tests, but passengers have also approved it regarding their perceived travel comfort and safety. Among others, the evacuation system in question has been used in the 3S aerial cableways installed in Sölden and Koblenz[1)].

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[1]It should be noted that the evacuation system concept described here, which involves so-called "bringing vehicles" (to final stations), can be generally applied to all types of overhead cable railway (systems) with swinging or monocable circulating systems, where vehicles (cars) are coupled and uncoupled to the driving cable (3S system) or to the driving and suspension cable, or remain permanently coupled to this cable.

This solution has also been used in the new 8-person gondola (car) cableway installed on Grasjoch in Montafon, Austria, as well as in Poland, in the new continuous traffic cable railways gondola cableway built parallel to the Solina Reservoir dam, launched in 2022 by Polskie Koleje Linowe S.A. Much earlier, in September 2013, a passenger evacuation system similar in terms of the solutions was installed in a system of double-cable swinging aerial cableway 15ATW "POLINKA" in Wrocław. The cableway has been routed over the Odra River and connects the Wrocław University of Technology areas and the student town on opposite river banks.

In the further part of the article, the authors will show the advantages of the new evacuation system in comparison with evacuation methods using specialized teams of rescuers and traditional evacuation techniques from heights, including evacuation along a rope, using ladders, from the air, etc.

2. General description of the evacuation system

The philosophy behind the new method of passenger evacuation is to duplicate (make redundant) all the functions carried out by important elements of the cableway equipment responsible for maintaining the continuity of movement of the cable (driven or driven and suspension cable) together with the cars attached to it. The applied solution enables continuous movement of this cable, regardless of the reason for its stoppage, e.g., caused by the failure of the main drive [17] or the standby drive (emergency drive 1). Duplication of the drives' functional elements and other equipment responsible for power transmission meets the redundancy requirements [10].

In addition, power generators are installed at the lower and upper stations of the Solina cableway. These generators can provide power to the ropeway technology in the event of a power failure in the grid. The aggregate in the upper (drive) station has sufficient power to safely bring passengers to the station using the main drive, another security measure.

It should be noted that in the event of failure of the main drive, every modern cableway still has a second type of drive available, called a standby or an emergency drive [10], [11], [12], [13], [14], [16]. The energy source powering this drive must be independent of the main drive's source [42]. The commonly used source of power supplying the main drive is the electricity drawn from the power grid. The standby/emergency drive is activated only in the event of a breakdown and is not used for normal passenger traffic. Usually, the independent source of powering the emergency drive is a liquid-fuel internal, adequate power combustion engine (diesel engine).

The most common solution for emergency power transmission is a hydrostatic hydraulic system with a control unit comprising a diesel engine, a pump, and a hydraulic motor that drives a cable drum either directly or indirectly. A hydraulic power unit controls the system. The second variant means using a generator set powering a separate emergency drive electric motor. However, cableway operation using the emergency drive is frequently and erroneously perceived as a part of the passenger evacuation process. It should be clarified that typical passenger evacuation occurs only when the cableway system cannot be restarted in any way (within a reasonable period). Passengers are evacuated from the vehicles (cars) by rescue teams or freed and transported to a safe place through a special rescue/evacuation vehicle [3]. Such an evacuation/rescue vehicle may be a separate cable car with its power transmission system, independent of the main and standby/emergency drive systems [10].

In the case of the "bringing vehicles" (to a final station) system, the bearings system of the drive and bull wheels are duplicated. Immobilized passengers are safely transported without leaving the car (gondola) en route. Since both bull wheels are equipped with emergency bearings, the cars (gondolas) are always ready to move due to the driving and suspension cable. The main drive and the standby/emergency drive are powered by independent energy sources [1], [2], [12], [23]. The main one draws the energy to power the electric motor directly from the power grid, while the second one (auxiliary) uses, for instance, a power generator. However, both drives share the same transmission elements for the main drive wheel. This causes a severe problem since in the event of a malfunction of both drives, resulting in the immobilization of the drive wheel, the movement of the driving and suspension cable is impossible. Also, failure of the kinematic thrust on the section from the main motor to the drive wheel or from the standby/emergency motor to the drive wheel, always via the main gearbox, will cause the cable car to stop if the gearbox is blocked [9] permanently.

The only way to restart the cableway is to transfer the driving force directly to the drive wheel. The drive shaft needs to be permanently disconnected from the wheel to be able to do this. When the evacuation drive is engaged, the drive torque to the drive wheel is transmitted from the motor and transferred directly via a pinion to a gear rim on the drive wheel. During the failure period, the drive wheel is seated on the main bearing or, in case of failure, on the standby emergency bearing. This way, the motion energy can be transferred directly to the drive wheel, bypassing all immobilized elements of the kinematic sequence of the main drive, the gearbox, and the standby/emergency drive. Also, if the main axle bearing of the bull wheel at a switch (return) station is damaged, it can be replaced by an emergency bearing. Also, at the switch station, a typical bull wheel is equipped with a gear rim that cooperates with the pinion of the emergency drive. This way, the cable system is equipped with a second, independent evacuation drive with an individual power source independent of the main and emergency drives.

Moreover, in case of a malfunction of the main and standby drives, the cableway system operator may undertake any organizational measures to ensure the immediate use of technical means. In accordance with generally accepted safety regulations, such an approach ensures the safe evacuation of passengers within a reasonable timeframe if the main drive system malfunctions. According to the "bringing vehicles" approach, evacuation by other methods and external means of transportation is no longer necessary.

During evacuation, according to the "bringing vehicles" approach, one ensures the highest mental comfort of passengers trapped in the cars along the route. The above-mentioned evacuation concept does not involve rescue teams either. Passengers are not commanded to leave the car (gondola). Hence, stress and additional risks are eliminated, including the hazard of falling from height during evacuation based on mountaineering techniques.

Thanks to the "bringing vehicles" concept (to the final station), there is no need for dramatic but costly rescue operations with the involvement of multiple services of the Fire Department, Police, Ambulance crews, etc. Cars (gondolas) with passengers remain in place and are simply directed to the stations by means of one of the alternative drive mechanisms. In addition, the technical personnel at all times have access to route pylons, where spare parts and special tools are stored and always available. This is of vital importance in case the cable has left the pulley (running gear) system and re-installation is necessary. The supervisory authorities have previously approved the evacuation system in question: TÜV Austria and TÜV SÜD Germany, among others. Figure 1 shows a diagram explaining the "bring vehicles" evacuation concept.

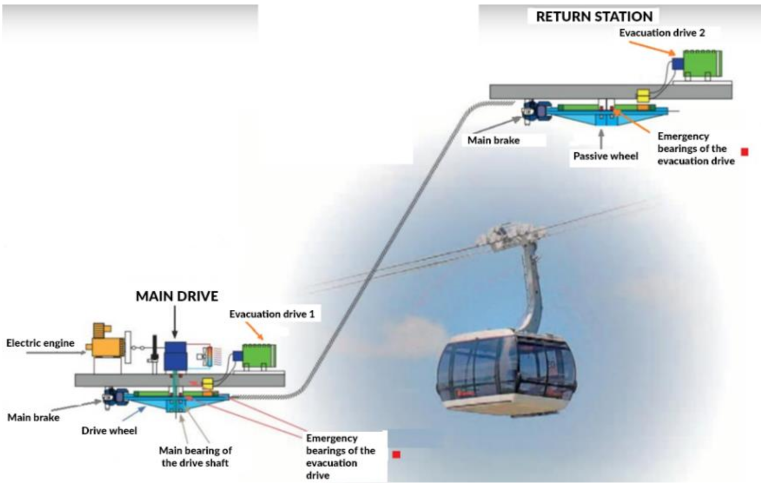

Fig. 1. Diagram of the evacuation concept – so-called "bringing vehicles" [5]

The main features of this evacuation system [6]: the main drive [12] is equipped with an auxiliary/emergency motor in case the main drive motor fails (evacuation drive 1); disengaging clutch, allowing the pulley to be disconnected from the remaining part of the drive chain in case the gearbox is blocked; each bull wheel is equipped with an emergency bearing to allow rotation, for at least one complete pass, in the event of blockage of the primary bearing; special equipment and tools installed on the route pylons, intended to lift the suspension cable with full vehicles (cars) onto the pulley battery (running gear) in the event it left the system; to remove cars blocked in stations certain special equipment (available at the stations), such as fixed crane and a set of tools, are used.

Figure 2 shows the double-row spherical roller bearings' location (green) for normal operation (main bearing), and on the other hand, emergency spherical roller bearings (emergency bearing) are marked in red.

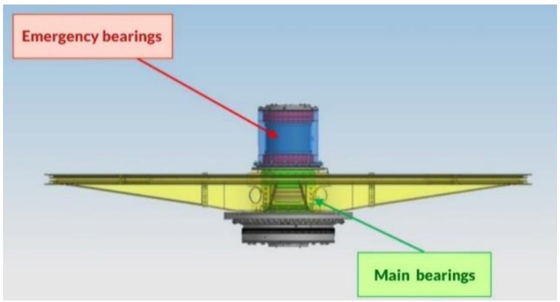

Fig. 2. Main and emergency of wheel bearings [4]

Figure 3 shows structure details and the two coexisting drive bearings - main and emergency. It should be noted that in the normal operation of the cableway drive, the emergency bearings are out of service (they do not rotate), although they do carry part of the load coming from the driving and suspension cable.

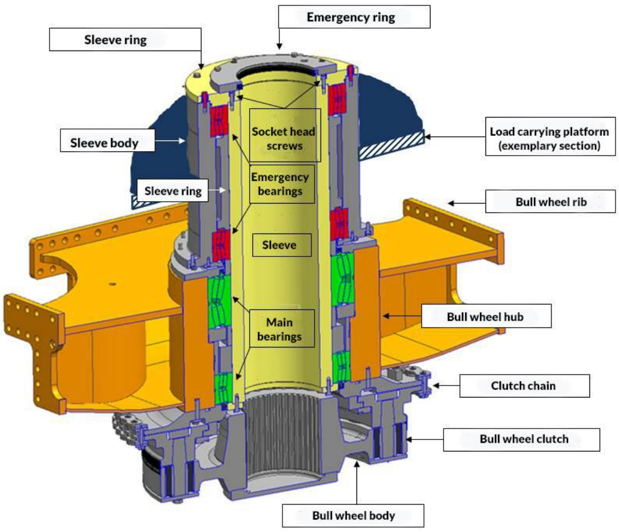

Fig. 3. Bull wheel mounting at the return station. Main (green) and emergency (red) bearings are seated on a common axis during normal operation. Emergency passive condition bearings [5]

In the case of the return station (the top station, according to Figure 1), the bull wheel is a passive element that carries the motion of the driving and suspension cable during normal operation. In the case of the drive station (bottom station, according to Figure 1), the cable (bull) wheel is the active element that transmits the movement of the driving and suspension cable during normal operation. A drive shaft (not shown in Figure 3) cooperates with the bushing (yellow) from above in this arrangement. This shaft is connected to the wheel body (gray) via a spline and a chain coupling. The entire body (gray) is attached to the drive wheel hub (orange) with screws. Two spherical roller bearings (green) are attached inside the drive wheel hub (orange). The inner race of each main bearing (green) is seated on a bushing (yellow). The upper part of the wheel hub (orange) is connected to the upper sleeve body (gray), which houses two emergency spherical roller bearings (red). Two spherical roller bearings (red) are also seated on the sleeve (yellow). The body of the upper sleeve 1 (gray) is fixed and permanently attached to the support structure of the drive station (not shown), with screws located around the perimeter of the flange of this body. Sleeve 1 (gray) and sleeve 2 (yellow) are permanently connected to each other through the emergency ring (gray), sleeve ring (yellow), and socket head bolts.

Transmission takes place in the following way as described below:

A. Normal operation: shaft→clutch, body→wheel, hub→main bearings (green)→ stationary sleeve (yellow)→*connected to the emergency ring* (gray) with socket head screws**.**

B. Emergency operation: chain→clutch, body→wheel hub→emergency bearings (red)→movable sleeve (yellow)→*not connected to the emergency ring* (gray) with socket head screws.

The socket head screws securing the aforementioned emergency ring (gray) get broken during the emergency operation.

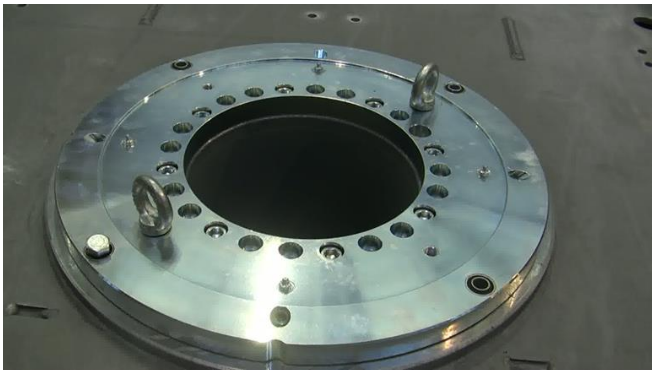

Fig. 4. Emergency bearing cover [6]

The two eye bolts in Figure 4 are used only to facilitate the installation/removal of the emergency bearing cover. The dual drive bearing system (redundancy) designed and presented here assumes at least two types of operational failures.

The first type of damage

In the event of seizing up or any other cause of serious and sudden damage to the primary (main) bearings and stoppage of the rotary motion of the sleeve and the bull wheel, the socket head screws screwed in from the front side, through the cover into the drive sleeve connecting to the ring, will be sheared (figure 5) due to the occurrence of a strong thrust torque.

Fig. 5. Sheared screws of the emergency bearing ring [6]

This, in turn, will cause the transfer of the rotational motion from this sleeve into the emergency bearings. The emergency bearings, which have been inoperative up to this point, take over the further rotation of the wheel, continuing the smooth movement of the wheel to move the motion of the driven and suspension cable.

The second type of damage

In the event of permanent immobilization of any of the elements of the kinematic system, starting from the electric motor of the main drive through the main gearbox and ending with the chain clutch, we can apply a direct drive to the wheel and thus affect the movement of the driving and suspension cable. However, this situation requires a manual disconnection of the clutch-toothed chain first. The sprocket of the auxiliary (hydraulic) motor will then be connected manually to the direct mesh of the motor pinion with the sprocket rim of the cable bull wheel. In this situation, the primary bearings perform their previous role and continue the rotary motion of the cable wheel.

The third type of damage (unlikely but possible to occur)

In the event of two hazardous situations, i.e., simultaneous occurrence of the first type of damage (damage to the main bearings) and blockage of the gearbox [9], which is theoretically possible but extremely unlikely, the emergency bearings will be activated automatically (by breaking off the socket screw bolts), and it will be possible to continue the rotary motion from the evacuation drive by disconnecting - with a chain clutch - the drive shaft from the electric motor of the main drive.

3. Analysis of the applied solution for compliance with the essential requirements

Pursuant to point 2.6.5 of Annex II to the Regulation [1]:

2.6.5. Measures shall be taken to ensure that the effects of a fire in the cableway installation do not endanger the safety of persons.

"For overhead installations in operation, priority should be given to persons on the line and the sensitivity of the cables to the effects of heat. This will often mean attempting to maintain the movement of the haulage rope to bring the persons to a station without delay. In any event, account must be taken of the possibility of cables breaking and falling, including those in the station opposite to that in which the fire has occurred. Fire outbreak and fire spread hazards shall be minimized in the design, operation, and maintenance of cable installations. The risk of endangering persons due to fire and/or any smoke emissions shall be minimized. In the event of fire [16], the installation shall be kept operational for as long as possible to ensure the rescue of persons".

Pursuant to point 7.2 of Annex II to the Regulation [1]:

7.2. Safety in the event of immobilization of the cableway installation. All technical provisions and measures shall be adopted to ensure that passengers and operating personnel can be brought to safety within a set time appropriate to the type of cableway installation and its surroundings when the cableway installation is immobilized and cannot be restarted quickly.

"The choice of installation type and arrangements for getting vehicles to a station or evacuating passengers must take into account the surroundings in general and the nature of the surfaces passed over in particular (water, glaciers, rocky cliffs, etc.)".

Therefore, can the evacuation system presented herein be accepted as sufficient and can successfully replace the typical evacuation based on the traditional means of evacuation, with the involvement of high-altitude rescuers and personal equipment for evacuation from height? One should always keep in mind a situation when this necessity might occur.

Certainly, other unconventional rescue means would be used in the course of a rescue operation, and one would have to take into account the need for a huge involvement of specialized rescue services. Including the use of a helicopter if other rescue means used would prove insufficient. Nevertheless, such a scenario of events should be considered as highly likely.

The collected comparative material from the actual evacuations carried out in Poland over the period of over 20 years [27], [28], [29], [30], [31], [32], [33], [34], [35], [36], [37], [38], [39], [40], clearly shows that the key element determining the success of the evacuation action is the total time for this task (T_{CE}) in connection with the number of people evacuated (P_{MAX}). Additional problems arise in the case of an aerial ropeway running across the river [27], as in the case of the Solina cable car.

Even with perfectly planned and efficiently carried out activities, the time of the on-site evacuation itself (T_{AE}) is, on average, not less than 1.5 to even 2-3 hours. In highly unfavorable conditions, it can be even longer. The main factors determining the success of the action are the weather, season, time of day, and the human factor, i.e., those that cannot be predicted.

The time of arrival (T_D) of rescue teams to the failure site is also important for the total evacuation time. In the case of mountainous regions, the T_D time may be from a dozen to several dozen minutes in the winter. The available time to remove the failure (T_{UW}) is assumed to be about 30 minutes from the moment of its occurrence. To put it simply, the total evacuation time using traditional methods is:

$$T_{CE} = T_{AE} + T_D + T_{UW} \tag{1}$$

where:

T_{CE} – total evacuation time for all types of cableways,

T_{AE} – "pure" evacuation time on site,

T_D – additional time taken into account in the winter season,

T_{UW} – maximum acceptable time to remove the failure

Under favorable conditions (small number of passengers and favorable weather conditions, a simple method of evacuation using ladders, a large number of rescue teams, good training, etc.) T_{CE} can be from about 90 minutes up to 210 minutes (legal limit) [3] in difficult situations.

The situation is completely different in the case of a redundant evacuation drive. Each of the drives can be started independently and from its own independent source of energy. The time from stopping the cableway to its restart, using any emergency drive. In the case of the Solina cableway, it takes about 5 minutes (starting at the upper station - Jawor) to about 15 minutes (when starting at the bottom station - Plasza).

Let us denote these times as T_{RJ} and T_{RP}, respectively. The time of disembarking from the vehicles (T_O), when driving with the evacuation drive at a speed of maximum 1 (m/s), route length approximately 1500 meters, and 34 vehicles (272 people in total) takes approximately 25 minutes. The total evacuation time using the Jawor station evacuation drive (T_{NEJ}) is:

$$T_{NEJ} = T_{RJ} + T_O \tag{2}$$

where:

T_{NEJ} – total evacuation time for Jawor station,

T_{RJ} – time for restarting for Jawor station,

T_O – time of disembarking from the vehicles.

T_{NEJ} *=30 minutes*

or total evacuation time using the Plasza station evacuation drive (T_{NEP}) is:

$$T_{NEP} = T_{RP} + T_O \quad (3)$$

where:
T_{NEP} – total evacuation time for Plasza station,
T_{RP} – time for restarting for Plasza station,
T_O – time of disembarking from the vehicles.

T_{NEP} *=40 minutes*

It can, therefore, be assumed that the T_{NEJ} or T_{NEP} evacuation times are approximate:
- 33% to 44% of the T_{CE} time (=90 minutes) under highly favorable conditions, or
- 14% to 19% of T_{CE} time (=210 minutes) under adverse conditions.

We can also estimate the time allotted for the evacuation of one person. It is expressed by the ratio of the total evacuation time (T_{CE}) to the number of evacuated people (P_{MAX}). Let's denote it as (*We*) and call it the evacuation factor. Therefore, the evacuation coefficient:

$$We = T_{CE} / P_{MAX} \quad (4)$$

where:
We – evacuation factor for all types of cableways,
T_{CE} – total evacuation time,
P_{MAX} – number of all evacuated people.

We know that in the Solina cableway, the maximum number of passengers P_{MAX} = 272 people was accepted for evacuation. The evacuation coefficient (*We*) is:
- drive of the Jawor station $We_{PJ} = T_{NEJ} / P_{MAX}$; We_{PJ}= 6.61 seconds/passenger (s/p);
- the drive of Plasza $We_{PP} = T_{NEP} / P_{MAX}$; We_{PP}= 8.82 seconds/passenger (s/p).

Let's compare them with the evacuation times conducted using traditional methods, which happened in previous years at popular ski stations. The evacuation coefficient $We=T_{CE}/P_{MAX}$ was: in the case of the Mosorny Groń cableway. Zawoja. Year 2004 (T_C=180; P_{MAX}=80); We_{MG}= 135 (s/p); in the case of the Szyndzielnia cableway. Bielsko-Biala. The year 2005 (T_C=180 minutes; P_{MAX}=20); In_{SZ}= 540 (s/p); in the case of the Słotwiny cableway. Krynica-Zdroj. Year 2013 (T_C=90; P_{MAX}=101); We_{KZ}= 53.46 (s/p).

A simple comparison shows that the evacuation rate in a traditional action, in relation to the method with evacuation drive systems used in the Solina cableway, is:
- We_{MG}/We_{PJ};135 (s/p) / 6.61 (s/p)=~20
- We_{MG}/We_{PP};135 (s/p) / 8.82 (s/p) = ~15

which is about 15-20 times bigger than the Mosorny Groń cableway, or
- We_{SZ}/We_{PJ}; 540 (s/p) / 6.61 (s/p)=~80
- We_{SZ}/We_{PP}; 540 (s/p) / 8.82 (s/p)=~60

which is about 15-20 times bigger than the Szyndzielnia cableway or
- We_{KZ} / We_{PJ}; 53.46 (s/p) / 6.61 (s/p)=~8
- We_{KZ} / We_{PP}; 53.46 (s/p) / 8.82 (s/p) = ~6

which is about 6-8 times bigger than the Słotwiny railway in Krynica Zdrój.

For the cableway on Słotwiny in Krynica Zdrój, based on the available data, a relatively low evacuation rate of {53.46 (s/p)} was obtained for 101 passengers, which would prove a fairly effective rescue evacuation. However, it should be borne in mind that the T_{CE} evacuation time, in this case, refers to the actual number of evacuated people, which does not necessarily mean the maximum number of P_{MAX} people to be evacuated (vehicles occupied by 100% passengers - no empty seats).

We know that the maximum evacuation time (T_{CEMAX}) is defined by the harmonized standard EN 1909 [3], which was fixed at 210 minutes, T_{CEMAX}=210 minutes (12600 seconds). We can set a maximum acceptable evacuation rate (We_{PA}) or the maximum number of evacuated P_{MAX} passengers:

$$We_{PA} = T_{CEMAX} / P_{MAX} \tag{5}$$

where:
We_{PA} – evacuation factor for all types of cableways,
T_{CEMAX} – maximum evacuating time limited through standard EN 1909,
P_{MAX} – number of all evacuated people, hence $We_{PA} \cdot P_{MAX} \leq 12600$.

For example, for a cableway that simultaneously transports P_{MAX}=100 people at the same time, the evacuation coefficient should be no more than We=126.

In the case of the Solina cableway, for the maximum allowable evacuation time T_{CEMAX}=210 minutes (12600 seconds) and the number of passengers $P_{MAX\text{SOLINA}}$=272, the We_{SOLINA} evacuation factor should be no more than:
$We_{\text{SOLINA}}=T_{CEMAX}/P_{MAX\text{SOLINA}}$; We_{SOLINA}=12600/272= 46 (s/p). This means that the obtained evacuation coefficient We_{SOLINA}=46 (s/p) is almost three times lower than the acceptable We_{PA}=126 (s/p).

Taking into account the best evacuation coefficient for the Słotwiny cableway in Krynica Zdrój (traditional evacuation), which was We_{KZ} = 53.46 (s/p) and translating it into the number of passengers ($P_{MAX\text{SOLINA}}$=272 people) for the Solina cableway (non-standard evacuation), the comparable evacuation time for the Solina cableway would be no less than:

$$T_{CE\ \text{SOLINA-KRYNICA ZDRÓJ}} = We_{KZ} \cdot P_{\text{SOLINA}} \tag{6}$$

where:
$T_{CE\ \text{SOLINA-KRYNICA ZDRÓJ}}$ – maximum evacuating time for Krynica Zdrój,
We_{KZ} – evacuation factor for Krynica Zdrój,
P_{SOLINA} – number of all evacuated people for Solina.

$T_{CE\text{SOLINA-KRYNICA ZDRÓJ}}$=53.46 x 272=14541 (s) > T_{CEMAX} =12600 (s). This means that evacuation using the traditional method would, in the most favorable case, be longer by at least $T_{CE\text{SOLINA-KRYNICA ZDRÓJ}}$ minus T_{CEMAX}= 14541(s)-12600(s)=1941 (s) = 32 minutes.

Referring purely theoretically to the evacuation on the Mosorny Groń cableway in Zawoja in 2004. $T_{CE\ \text{SOLINA}}$ calculated data from the evacuation of the Mosorny Groń cableway.

$$T_{CE\text{SOLINA-MOSORNY GROŃ}} = We_{MG} \cdot P_{\text{SOLINA}} \tag{7}$$

where:
$T_{CE\text{SOLINA-MOSORNY GROŃ}}$ – maximum evacuating time for Mosorny Groń,
We_{MG} – evacuation factor for Mosorny Groń,
P_{SOLINA} – number of all evacuated people for Solina.
$T_{CE\text{SOLINA-MOSORNY GROŃ}}$ =135 · 272=36720 (s) > T_{CEMAX} =12600 (s)
This means that evacuation using the traditional method would, in the most favorable case, be longer by at least:
$T_{CE\text{SOLINA-MOSORNY GROŃ}}$ minus T_{CEMAX}= 36720 (s) -12600 (s)=24120 (s) = 402 minutes = 6 hours 42 minutes.

Referring purely theoretically to the evacuation on the cableway to Szyndzielnia in 2005. T_{CE}SOLINA calculated for data from the evacuation of the Szyndzielnia cableway.

$$T_{CE\text{SOLINA-SZYNDZIELNIA}}=We_{SZ}\cdot P_{\text{SOLINA}} \quad (8)$$

where:

$T_{CE\text{SOLINA-SZYNDZIELNIA}}$ –maximum evacuating time for Szyndzielnia,
We_{SZ} – evacuation factor for Szyndzielnia,
P_{SOLINA} – number of all evacuated people for Solina.

$T_{CE\text{SOLINA-SZYNDZIELNIA}}$ =540 ·272=146880 (s) > T_{CEMAX} =12600 (s)

This means that evacuation using the traditional method would, in the most favorable case, be longer by at least:

$T_{CE\text{SOLINA-SZYNDZIELNIA}}$ minus T_{CEMAX}= 146880(s)-12600(s)=134280 (s)=2238 minutes = 37 hours.

In the three cases mentioned above, extremely favorable conditions for the railways where the failures occurred were adopted for comparison purposes. Above all, due to the diametrically different parameters of the above-mentioned cableways, including favorable conditions for vehicle access from ground level and the number of route supports. The more support, the better the evacuation conditions. In the case of Cableway Solina, we are also dealing with the area of a hydroelectric power plant and its energy infrastructure. This, in turn, results in no or no access from ground level to vehicles and means a limited number of route supports. These factors would also hinder the evacuation operation using rescue teams. First of all, it would involve the limitation of introducing a larger number of these units at the same time on the cableway route.

Reliable European Union sources [41] state that, for example, the Czech Republic requires all passengers to be evacuated in an emergency within 2 hours (T_{CEMAX} =120 minutes) rather than 3.5 hours (210 minutes), which is the common requirement in other EU countries. This caused a delay in the acceptance of the gondola cableway in the Czech Republic (also in Poland), which the manufacturer delivered. Approval was put on hold until the design was changed to include a fifteen-passenger emergency vehicle instead of the originally planned nine.

The example above shows that the manufacturer was forced to use an evacuation vehicle with increased capacity. The original design assumed the technical means of evacuation referred to in [1] and [2] as standard evacuation equipment of the reversible cableway. Because the maximum T_{CEMAX} evacuation time in the Czech Republic has been set at 2 hours (120 minutes = 7200 seconds). So, we only have about 57% of the time needed to evacuate 100 passengers from a comparable reversible cableway with identical parameters as the one operated in Poland. The discussed coefficient We for the same number of P_{MAX} = 100 passengers is in the Czech Republic respectively: We=7200/100=72 (s/p).

4. Summary

The essential needs and benefits of the new system for evacuating passengers trapped in overhead cable cars are presented. The presented evacuation system has been designed for rescue teams and passengers in case of very limited, difficult, and hazardous access to vehicles (cars) and passengers during a sudden stoppage of the overhead cable car traffic.

Both the evacuation coefficient We discussed above and the obtained results of evacuation times T_{CEMAX} are for illustrative purposes only. Calculated evacuation times for the evacuation of one passenger, i.e., coefficient We{e.g., We_{KZ}=53(s/p)}, do not mean that the first passenger will be evacuated during a traditional rescue after 53 seconds. It is obvious that the time to reach the evacuation site (T_D) and the next minutes for freeing the first person is of key importance here. The obtained We calculations should, therefore, be approached with a certain margin of tolerance. Nevertheless, the We coefficient makes it possible to estimate whether the adopted evacuation assumptions are appropriate and sufficient to comply with the evacuation of all P_{MAX} passengers during T_{CEMAX} time.

Requirements:
- the need to keep all cableway drives ready and operational at all times,
- obligation to periodically perform test runs of the cableway evacuation system with the use of doubled (redundant) elements [23],
- provision of necessary technical and material resources for evacuation and keeping them ready and operational at all times within the cableway system [19], [21], [24], [25],
- employment of competent, professional, and trained technical personnel with high awareness of the operations and implementation of a regular training schedule [21].

Advantages:
- immediate evacuation action thanks to the ability of easy and safe access to surplus (redundant) components,
- passenger-acceptable increase in travel time if drives are swapped, and the evacuation drive is activated,
- making the timing of the evacuation independent of other negative external factors such as wind, rain, snow, icing, limited visibility [3],
- elimination of the stress factor for passengers during the necessary evacuation from heights based on mountaineering techniques from great heights,
- lack of need for evacuation/rescue teams, which means the elimination of hazards [18], [20], [22] relating to the rescuers of these teams,
- launching a technical, professional, and safe means of evacuating passengers with a high degree of operational reliability as a priority,
- extremely low probability of evacuation drive failure due to the redundant drive systems (two emergency drives) characterized by high reliability.

It is difficult to assess the costs of each evacuation with the use of rescue teams, the damage caused by the evacuation of people from a height, and the possible costs of their treatment, also taking into account psychological care.

Nevertheless, it seems that the implementation of modern methods of evacuation is more effective and safer than traditional methods.

Figure 6 shows the selected and key elements of the cableway and the KL Solina evacuation drive.

Fig. 6. Jawor station. General view [43]

Inside the drive pulley, you can see the gear ring(cogwheel) and the rack of the emergency drive (Figures 7 and 8).


Fig. 7. Jawor station. Platform. Main drive pulley [43]

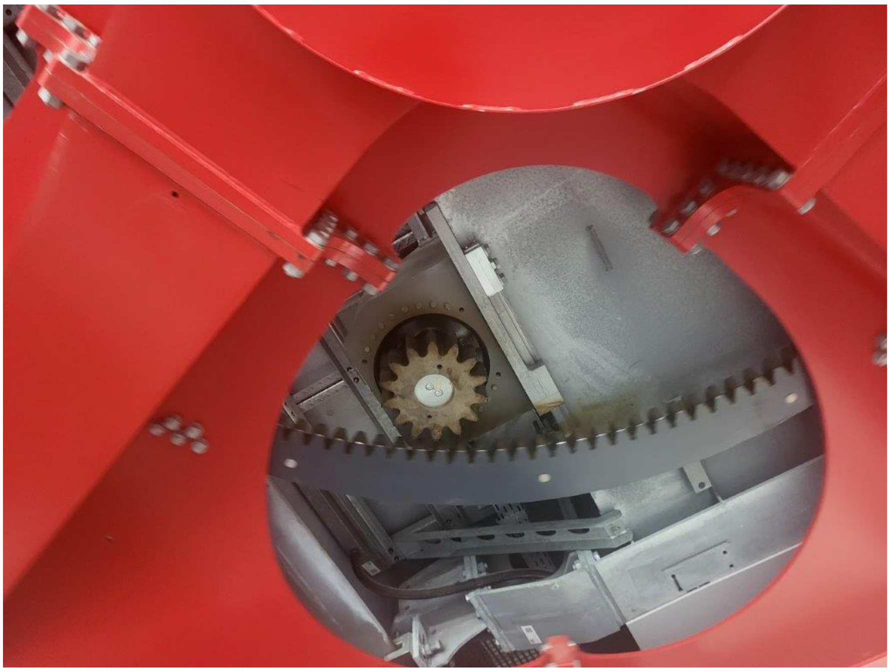

Fig. 8. Jawor station. Main drive pulley. The gear ring and rack of the emergency drive [43]

In the event of a main drive failure, the gear ring is connected to the rack of the emergency drive. Figure 9 shows the state before these elements were connected - visible lack of engagement (normal operation of the cableway).

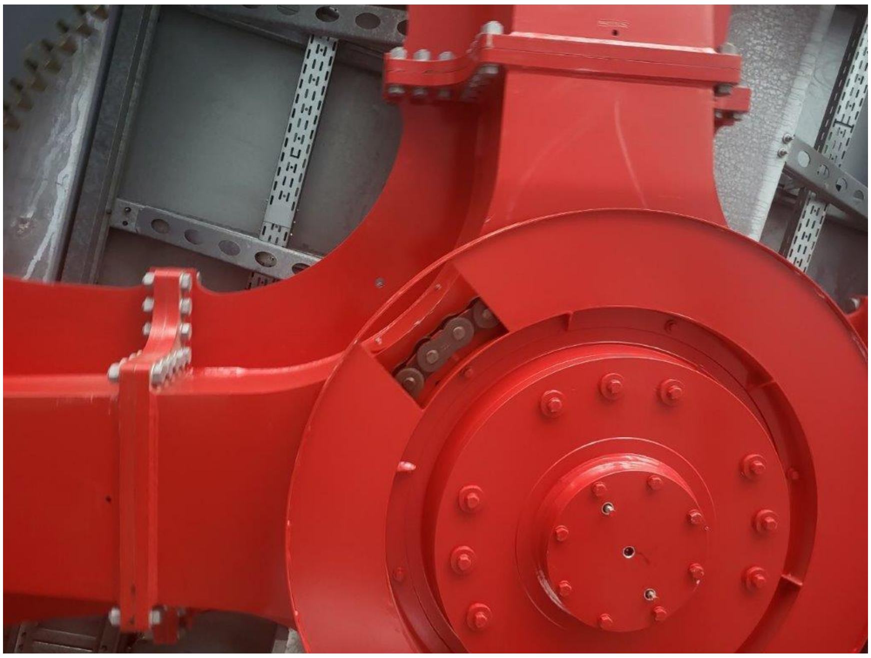

Fig. 9. Jawor station. Chain clutch-the ability to switch the main bearing to the emergency bearing [43]

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