Article

Cable Car with Central Entry and Exit

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Abstract: This paper will present a new concept of cable cars with central entry and exit. First, existing systems of cable cars and their properties will be presented and advantages of the new concept will be explained. The new concept utilizes solution geometry as the basis of the idea. 3D computer graphic tools were used for the design. In the second part of the article the geometric procedure of the design of the rope flow curve in the station is presented. This is necessary in order to stop the cabin steadily in the central position. If the station is designed in such a way that passengers enter and exit on a stationary platform separate from the device, the capacities of the device can be large. In this case, passengers entering and exiting do not interfere with the other passengers who are traveling with the cable car on the line.

Keywords: cable cars; cableways; gondolas; geometric modeling; computer graphics; descriptive geometry; capacity; boarding

1. Introduction

According to the operating principles, aerial cable cars are divided into aerial tramways and gondolas.

Aerial tramways transport passengers using only two cabins which stop at stations. When the first cabin is at the upper station, the second is at the lower station. Their maximum speed is 12 m/s or 43.2 km/h. [1] With only two cabins, they can overcome greater inclines than gondolas; the span between the pylons can be extraordinarily long (more than 1 km) so they can overcome major gaps and precipices, and they are suitable for distances up to 3 km. The cabins stop completely at stations, so passengers have enough time to enter or exit. As only two cabins are available, they have small capacities (200 persons per cabin, maximum 2,000 persons per hour), and the average waiting time of passengers at the station is longer. The times of entry and exit (dwell times) also are longer than gondolas. The disadvantage of aerial tramways is that device must completely stopped during ingress and egress. [2]

Gondolas are unidirectional aerial cable cars with circulating vehicles (cabins). They consist of several cabins that can carry up to 30 persons each and have greater capacities than aerial cars - up to 4,000 persons per hour. The speed is slower than aerial cars, with a maximum of 7 m/s for bi-cable gondolas and a maximum of 6 m/s for monocable gondolas. [1] Dwell times are shorter than aerial cars as the cabins are smaller. Passengers do not need to wait for the vehicles at the station, as the vehicles constantly come and go. The spans between the pylons are smaller than aerial tramways because there is more than one vehicle on the rope at a time, and the lengths of gaps and precipices over which cabins can travel are smaller than for the aerial tramways. The time available for entering and exiting the cabin is limited by the speed and length of the platform. The disadvantage of gondolas is that when they are at a station, cabins do not stand still but move slowly through the station, which can make it difficult for persons with disabilities and older adults to enter. [2]
Chairlifts with fixed grips have a maximum speed through the station of 2.5 m/s (with no transport conveyor at the entrance). [1] These chairs travel with the same speed as the rope, so the chairs quickly travel through the station and entrance for skiers or passengers is difficult. Depending on the performance they are very simple and inexpensive.

Gondolas with cabins and chairlifts with detachable grips have reduced speeds through the station - 0.5 m/s [1] - and entrance for skiers and passengers is easier. The design of the unidirectional gondola with detachable grips is much more expensive, since the station has a conveyor which decelerates, moves and accelerates the cabins through the station when they are detached from the rope. Therefore this type of cable car is very expensive (figure 1).

**Figure 1.** Existing system of gondolas – passenger entry and exit at station. [2]

Both systems have advantages and drawbacks, leading to the question of whether a cableway device could be designed that contains the advantages of both systems:

- The system should have a high capacity containing more vehicles.
- Vehicles should stop at the station and, at the same time, the vehicles on the line of the cable car would travel smoothly along the line. This would make entry and exit very easy.
- The design should be simple (without special conveyors to decelerate, accelerate and move cabins through the station).

The desired properties of the cableway devices can be achieved with a new invention, whereby a special form of attachment of the suspension to the cabin is used in a precisely determined length of the suspension. By using geometric solutions and kinematics, fixed grips for fixings on the rope can be used.

The idea was presented for the first time at the Department of Transportation Engineering (Faculty of Civil Engineering, Transportation Engineering and Architecture) at the University of Maribor on 4 June 2014, where sketches were shown. [3]

The solution is presented in the left sketch (a) of figure 2. The cabin for gondolas is in the middle and the rope with suspension in a horizontal position is rotating around the standing cabin. In this way passengers can enter and exit the cabin, which is not moving, allowing for its use by people with disabilities.

The right sketch (b) of figure 2 demonstrates the solution where people can enter and exit from an extra separate platform which is not connected with the cabin at the station. In this way passengers have enough time for enter and exit and they do not interfere with other moving cabins on the line. When vehicle comes into the station it must attach to this platform with passengers.
2. Methodology

Throughout history, those who wanted to present their ideas or innovations were required to be good painters, so that they could explain their ideas to the rest of the world. Leonardo da Vinci drew his ideas and Fausto Verancio (Faust Vrančić in Croatian), who, in his book Machinae Novae from 1616, presented the drawing of the first cable car (ropeway) in Europe. Nowadays, other efficient tools can be used for the presentation of ideas, such as computer graphics and 3D modelers.

For this new operating model of a cable car with central entrance and exit, a geometrical model of a station was developed that included all the essential elements that affect passenger entry and exit. A CAD program was used for implementing this geometric model, with the possibility of 3D modeling. Based on the geometric model, a new proposed model was established with improved characteristics for calculating the geometry and capacities and other properties of cable cars. First, a geometric design that included the new ideas presented in this paper was implemented within the 3D geometric model. Then the geometric procedure of design of the “rope flow” curve in the station was established using descriptive geometry. This curve is necessary to stop the cabin steadily in the central position.

3. Results

One year elapsed from the idea presented in figure 3 to the construction of the 3D computer model. Through consultation, two variants of the model were developed. The first is a simple and inexpensive cable car implementation for the transport of a small number of passengers and the second is a more complicated version with a higher capacity. For this second version the geometric procedure of the rope flow curve is established.

3.1. Model of a cable car system with central entry and exit

The model of the cable car system with central entry and exit is presented as a static computer 3D model in figure 3. A patent application for this kind of cable car was submitted.
3.1.1. Description of the operation

Figure 3. 3D computer model of a cable car with central entrance and exit at a station.

- Suspension (L – length of suspension)
- Attachment element (connection between cabin and suspension)
- Fixed grip (connection between suspension and rope)
- Cabin
- Drive wheels (or return wheels)
- Supporting wheels
- Deflection wheel
- Carrying/hauling rope

Figure 3 presents a new concept of a unidirectional cable car with central entry and exit, consisting of several cabins. At the station, cabins are completely stopped while other cabins outside move along the track. The construction concept is simple: it uses fixed grips and does not require conveyors for braking, transporting and accelerating cabins at a station. Only supporting wheels, which are free and do not need extra drive, are needed.

The base for the invention of the circular cable car with central entry and exit is the length of suspension L that connects the cabin and the fixed grip, which is also the distance between the center of the upper part of the cabin and attachment to the rope. The distance L is equal to half of the diameter D of the rotation of the rope at the station. Circulation of the rope at the station is enabled by drive wheels or return wheels (or one big drive wheel or return wheel is sufficient), which form a half circle with diameter D.

\[ L = \frac{D}{2} \]

L – length of the suspension (m)
D – diameter of the rope rotation in station (m)

The ratio allows a cabin to arrive to station by guiding it to the center of the half circle (around which a carrying/hauling rope moves) with the help of supporting wheels. During this process the
suspension moves from a vertical position to the horizontal position. In this way the cabin stops in
the station while the fixed grip and rope rotates around the drive or return wheels. As the
suspension turns around, the cabin is in a central position and allows passengers to exit and enter
the cabin.

When the suspension is in an inclined or horizontal position rotated 180° (figure 4a), the cabin
starts to move with the help of the support wheels and leaves the station. The suspension is again
placed in the vertical position. This design is possible with a special attachment of the suspension on
the cabin which allows for an incline of 90° (from the vertical to the horizontal position) and for the
rotation of the suspension in the horizontal position around the cabin (figure 4b). When the cabin is
out of the station (on the track), the incline of the suspension must be disabled.

With this invention, vehicles can be stopped in the station at circular cableways with fixed grips
and passengers can exit or enter smoothly. The implementation of the circular cableway with fixed
grips is cheaper than a circular cableway with detachable grips.

![Figure 4. Ground plan of the station with rotating suspension (a) and front view of the cabin with inclining suspension (b)](image)

3.1.2. Size of device

Figure 3 and figure 4 raise the question of the size of the system. If the cabin is for four
passengers, six seconds is enough to empty the cabin through the right door and for loading the
cabin through the left door. Six seconds is the time the cabin stands in the central position. The
velocity of this cable car with fixed grips is 2.5 m/s – like chairlifts with fixed grips. The rope with
fixed grip has six seconds to traverse the following length:

$$l_s = V_C \cdot t_s = 2.5 \cdot 6 = 15s$$

where:

- $l_s$ - length of path which is made by the rope during the 180° rotation (m)
- $V_C$ - speed of the cable car (m/s)
- $t_s$ - time cabin is stationary in station - time for entry and exit (s)

The length of the suspension, which is half of the diameter of the circle, is determined by the
following formula:

$$L = \frac{D}{2} = \frac{l_s}{\Pi} = \frac{15}{3.14} = 4.77m$$

![Diagram](image)
The abovementioned cable car with central entry and exit requires a station that is at least 9.54 m wide. If the cabin in the central position is replaced with the next cabin every eight seconds, then the capacity of the cable car is:

$$Q_c = \frac{3600}{\Delta t_c} \cdot n = \frac{3600}{8} \cdot 4 = 1800 \text{ persons/h}$$

$$Q_c$$ - capacity of the cable car (persons/h)

$$\Delta t_c$$ - interval between cabins (s)

$$n$$ - number of persons in the cabin (persons)

If we want bigger cable cars with central entry and exit, for instance eight persons in the cabin, then the cabin must stay in the central position for 10 seconds, the length of suspension ($L$) would be 7.96 m and the width of the station should be about 20 m. The capacity with a 12 second interval between cabins will be 2400 persons/hour. The station must double in width for a 33% increase in capacity, so this type of cable car is not suitable for higher speeds and larger cabins. It is suitable for a capacity up to 1800 persons/hour and for a velocity of up to 3 m/s.

### 3.2. Model of a cable car system with attaching platforms in a central position

If passengers can enter and exit from special platforms in the station that are detached from the cabin, then the cable car can reach large capacities. Idea is that entry and exit is separate in the stationary platform. When the cabin arrives into the station it attaches to a platform full of passengers. This kind of device provides passengers with enough time to enter and exit and at the same time, the vehicles on the line of the cable car would travel smoothly along the line.

**Figure 5.** 3D computer model of cable car with attaching platforms in a central position

1 – Suspension ($L$ – length of suspension)
2 – Attachment element (connection between cabin and suspension)
3 – Fixed grip (connection between suspension and rope)
4 – Cabin
5 – Drive wheels (or return wheels)
6 – Platform
7 – Deflection wheel
8 – Carrying/hauling rope
3.2.1. Description of the operation

Figure 5 is a model of a cable car system where the cabin attaches to a platform when in the central position. The operation is similar to the cable car with central entry and exit. When the cabin enters the station, it moves to the middle of the line at the same time that the rope is guided down so the suspension can come to a horizontal position. This is more comfortable for passengers because the cabin is always on the same level. When the suspension is in the horizontal position the fixed grip with rope rotates around the curve (it is not circular, but an elliptical curve). With this curve the cabin in the middle can slow down. First the platform which came into the station detaches from the cabin. When the platform is detached from the cabin it is moves with a conveyor to the position where can passengers can smoothly exit and enter. When the cabin is stopped at the central position, it can attach to the next platform full of passengers. After attaching to the platform the cabin accelerates and leaves the station. The special curve of the rope flowing provides deceleration and acceleration for the cabin in the station. This kind of cable car uses fixed grips. If the length of the suspension is 8 m, then the station width must be a minimum of 16 m. When the cabin with attaching platforms leaves the station, the suspension sinks into the platform. In this way the connection between the cabin and platform is more secure on the line.

If the platforms have a capacity of 100 passengers and every 30 seconds one platform can be attached to the cabin, then the total capacity of this kind of cable car can reach 12,000 passengers per hour. This type of cable car can have a middle station, because the platform can detach from the ending station of the first line and then moves with a conveyor to the starting station of the second line.

3.2.2. Geometric procedure of the design of the “rope flow” curve

This type of the cable car decelerates and accelerates the cabins only with the geometric shape of the carrying/hauling rope on which the cabins are connected with fixed grips. Thus the rope must flow on the special curve which is provided with drive wheels. To get this curve of flowing rope in the station a geometric procedure for design using descriptive geometry is required. This curve is necessary in order to stop the cabin steadily in the central position.

This shape of curve allows the cabin at the middle of the line in the station to decelerate while rope and fixed grip moves around the curve with constant speed. Constant maximum deceleration or acceleration for cable cars can be 0.5 m/s². [5] If the speed of cable car is 5 m/s and the length of suspension is 8 m, then the procedure for curve design is as follows:

\[
\text{a} = \frac{\Delta V}{\Delta t} = \frac{5}{10} = 0.5m / s^2 
\]  

(5)

The cabin at the middle position needs 10 seconds to stop from speed \( V_c = 5 \text{ m/s} \) (figure 6).

During the first second the speed of cabin falls from 5 m/s to 4.5 m/s. In this first second the cabin makes the path:

\[
\Delta S_1 = \frac{V_1 + V_2}{2} \cdot \Delta t = \frac{5 + 4.5}{2} \cdot 1 = 4.75m
\]  

(6)

During the same first second the rope travels a distance of 5 m (with a speed of 5 m/s)

\[
\Delta L = V_c \cdot \Delta t = 5 \cdot 1 = 5m
\]  

(7)
Figure 6. Basis for the calculation for deceleration of the cabin to the center position.

During second two the speed of the cabin falls from 4.5 m/s to 4 m/s and travels:

\[ \Delta S_2 = \frac{V_2 + V_3}{2} \cdot \Delta t = \frac{4.5 + 4}{2} \cdot 1 = 4.25 \text{m} \] (8)

Also during second two the rope travels \( \Delta L = 5 \text{ m} \) (with speed 5 m/s)

During the third second the speed of cabin falls from 4 m/s to 3.5 m/s in this third second the cabin travels:

\[ \Delta S_3 = \frac{V_3 + V_4}{2} \cdot \Delta t = \frac{4 + 3.5}{2} \cdot 1 = 3.75 \text{m} \] (9)

During the same third second the rope travels \( \Delta L = 5 \text{ m} \) (with speed 5 m/s).

Such calculations can be made for the further seconds of the deceleration of the cabin at the middle of the line. The construction of the curve (figure 7) begins at the time \( t=0 \), when the cabin begins decelerate and the velocity of the cabin is 5 m/s. The cabin is at point A₀ and the fixed grip on the rope is in point D₀. The distance between these two points is \( L=8 \text{ m} \). This is the length of the suspension. In the first second, from time \( t=0 \) to time \( t=1 \), the cabin travels \( \Delta S_1 = 4.75 \text{ m} \), so the distance from A₀ to A₁ is 4.75. At the same time the rope travels \( \Delta L = 5 \text{ m} \), so the distance between D₀ to D₁ is 5. The intersection between an arc with radius \( L=8 \text{ m} \) with its center at A₁ and an arc with radius \( \Delta L = 5 \text{ m} \) gives the point D₁. From point D₁ to point D₂ is again \( \Delta L = 5 \text{ m} \). From the point A₁ to A₂ is a distance of \( \Delta S_2 = 4.25 \text{ m} \). The intersection between an arc with radius \( L=8 \text{ m} \) with its center at A₂ and an arc with radius \( \Delta L = 5 \text{ m} \) gives the point D₂. And again the intersection between an arc with radius \( L=8 \text{ m} \) with its center at A₃ and an arc with \( \Delta L = 5 \text{ m} \) gives the point D₃. This procedure can be continued, and where the points D connect with lines, we can get the polyline. But these points can also connect with spline which modern geometric modelers like Autocad have.
When this curve is mirrored over the horizontal line at the middle of the station, we can get the curve for acceleration for the cabins which attach with the platform and both leave the station.

4. Discussion

The cable car with central entry and exit has several advantages and disadvantages. The advantages of this type of device are the simple and cheap design, and the fact that cabins would stop at the station and, at the same time, the cabins on the line of the cable car would travel smoothly along the line. This would make entry and exit very easy for older and disabled persons. This type of cable car does not need conveyors for decelerating, moving and accelerating the cabins through the station because these functions are performed by the rope.

The disadvantages for this type of system are a reduced capacity and limited time for passenger entry and exit. The speed of the cable car is slow (2.5 m/s like chairlifts with fixed grips) and cabins must travel up at the station because the suspension has to be in a horizontal position for rotating. A better solution may be that the rope travels down in the station and cabins are at the same level, as in figure 5 where an advanced type of cable car with similar operation is presented. Cable cars with central entry and exit cannot have middle stations and they need a lot of space for stations.

On the other hand, the cable car with attaching platforms in the central position also does not need conveyors for deceleration, movement and acceleration of the cabins through the station. When the cabin reaches the middle position it can decelerate with the geometry of the “rope flowing” curve. The advantage of this kind of device is that the platform can separate from the cabin and passengers can exit and enter smoothly while the cable car system continues to operate and transport cabins on the line.

6. Patents

On 12 August 2016 a patent application was submitted for the “Cable car with central entry and exit” at the Office of the Republic of Slovenia for Intellectual Property. The authors of this paper are the inventors.


3. Težak, S. *Ropeways in clean urban transport* - presentation (University of Maribor, Faculty of Civil Engineering, Transportation Engineering and Architecture); Available online: http://www.fg.uni-mb.si/tec/tec/attachments/article/190/08_Tezak.pdf (accessed on 10 October 2017).
