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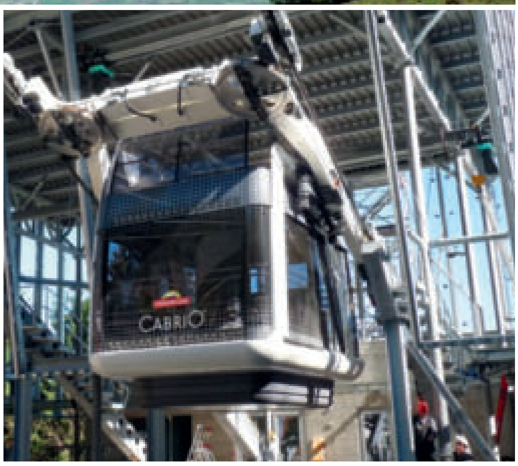
Ready, steady, Cabrio!

GARAVENTA The new jigback to Stanserhorn will be officially opened on 29 June. The Garaventa aerial tramway with cabins supplied by Gangloff has been rightly acclaimed as a world first.



PHOTOS: STANSERHORNBAHN

There have been several articles on the innovative engineering and design employed for Stanserhorn's new jigback in previous numbers of ISR. Often enough, the accolade "a world first" is employed for details which, although new, are not particularly exciting. That is certainly not the case with the new cabriolet jigback known as the Cabrio-Bahn; there are so many innovations packed into this aerial tram that the result is hard to describe in conventional language. We have nevertheless done our best in the following.

With regard to the ropeway system, the Cabrio-Bahn is a two-car reversible with twin wide-gage track ropes and two haul rope loops located beneath them. The haul rope loops impart traction via sheaves attached to the cars, as in the case of the Funifor system. Unlike a Funifor, however, which is also a reversible tramway with wide-gage track ropes, the cars travel between and not beneath the track ropes, which means there are no ropes at all located above the cars. The thinking behind this unusual solution was to permit the system to operate with double-decker cars with an open top deck. That is what makes the Cabrio-Bahn a world first in the eyes of the layman. It also means that the cabriolet car does not have a hanger as in the case of a conventional aerial tramway cabin but rather a frame with a carriage on either side, in which the double-decker car rests in a self-leveling mechanism. The pivot point for the cabin in the frame is located just above the floor level of the top deck. To the ropeway engineer, it is clear that such a system must of necessity present a number of problems, and the design engineers at Garaventa and Gangloff did an excellent job of solving them. One such problem relates to the rope configurations.

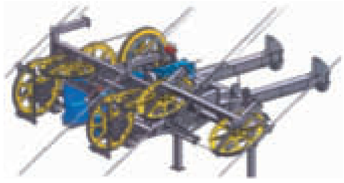
THE TRACK ROPES

The Cabrio-Bahn has four permanently anchored, fully locked track ropes with a nominal diameter of 66 mm. This large diameter – and the high rope tension – is interesting insofar as the car has a maximum laden weight of 160 kN, and at approx. 120,000 kN per track rope, rope tension is much higher than required by the codes for transverse loading of the track ropes by the cars. This high level of rope tension was selected in order to minimize fluctuations in sag under operating conditions and hence track rope displacement on the saddles of the four towers. In the case of pronounced fluctuations in track rope sag or unequal rope movement on the saddles caused by minor differences in friction, it is theoretically possible that the cars could approach the towers slightly out of perpendicular. For passengers, the result would be extremely unpleasant lateral acceleration as the cars jerk back to the perpendicular on passage over the tower (something that does not happen with a conventional jigback cabin because of the hanger and the resulting swing). As the ride experience was a primary focus of the project, the decision was taken to use outsized track ropes so as to avoid any reduction in the quality of the ride as far as possible.

The same applies to the choice of saddle radius: In the interest of the quality of the ride, it is much larger than required for the diameter of the track ropes alone. As a result, and also for other reasons, a solution had to be found to guarantee accurate positioning of the track ropes on the towers. To ensure that they are correctly aligned with the saddle grooves without any lateral fleet angle, pivoting extension arms were mounted on horizontal axles at both ends of the saddles. The track ropes are held in grips – not unlike slack carriers – fitted to the outer ends of the extension arms, which limits track rope movement on the saddles to the perpendicular plane from that point on.

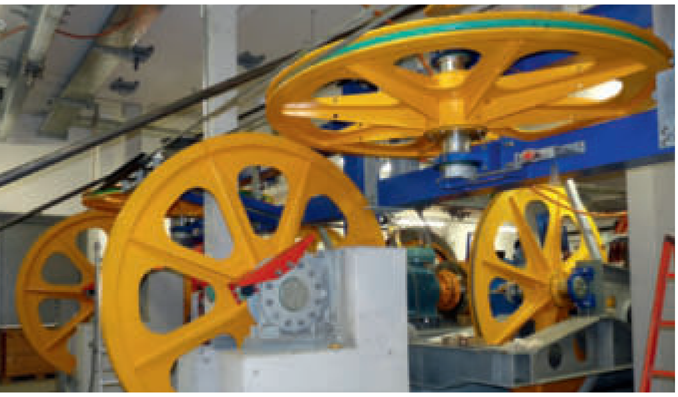
In this connection it should be noted that the cars on the Cabrio-Bahn are not fitted with track rope brakes. This is explained by the fact that the upper and lower haul ropes are both continuous loops, so that the installation is in compliance with cableway standard EN 12929-2 for reversible installations without track rope brakes. With no track rope brakes to consider, it was possible to select 180° for the contact angle of the rope grooves

FIGURES



Please turn to page 10 for figures

- Fig. 1: Axonometric schematic of the rope configuration in the bottom station
- Fig. 2: Cross-section of the rope configuration in the bottom station (blue: track ropes, red: lower haul rope, green: upper haul rope)
- Fig. 3: Plan view of the complete rope configuration (blue: track ropes, red: lower haul rope, green: upper haul rope)
- Fig. 4: Rope configuration for the upper haul rope (green) in the top station in a sectional view transverse to the axis of the line, with the haul rope counterweight at the bottom of the pit
- Fig. 5: Rope configuration for the upper haul rope in the top station in a sectional view in the axis of the line, with the haul rope counterweight at the bottom of the pit (blue: track ropes, red: lower haul rope, green: upper haul rope)
- Fig. 6: Haul rope configuration at the cars (red: lower haul rope, green: upper haul rope)



Top: Top station nearing completion

Bottom: The complicated haul rope configuration in the machine room involves two twin-groove bullwheels, two secondary sheaves and six deflection sheaves.

on the tower saddles, which is an optimum solution for track rope safety.
Another advantage of the decision to position the cars between the track ropes is the fact that visual inspections can be performed from the cars more easily and more reliably than on other ropeway systems.

THE HAUL ROPES

The drive is located in the bottom station on the left side of the line looking uphill. It comprises two induction motors supplied by two inverters (with the electrical components from Frey AG). Figure 1 is a schematic of the rope configuration with the drive in axonometric view. It is complicated, with the continuous loop of the lower haul rope guided onto the line via no fewer than six deflection sheaves from two twin-grooved bullwheels with a secondary sheave each, all the more so as the right bullwheel and secondary sheave are not even shown. The rope configuration is clearer in the cross-sectional view of the bottom station in Figure 2 and in the plan view of the complete rope setup in Figure 3, although, due to rope superimposition and in the interest of clarity, not all sections of the haul rope are color-coded.
The rope tensioning system is located in the top station, where the rope configuration is relatively simple. Each of the four incoming sections of the upper haul rope loop passes over two deflection sheaves to the counterweight assembly, where they form two pairs on four return sheaves. Figure 4 shows the upper haul rope setup in a sectional view of the top station transverse to the axis of the line, with the view in the axis of the line shown in Figure 5.
That brings us to the haul rope setup at the cars (Fig. 6). This resembles the Funifor system, with two return sheaves each for the upper and lower haul ropes. The sheaves are located in vertical pairs on the cross member of the carrier frame. In the normal case the sheaves are only there to compensate any force differentials and hardly move at all. In the event of a fault in one of the two bullwheels, however, the defective bullwheel can be taken out of service and the cars returned to the stations using the remaining bullwheel and the functioning section of the lower haul rope, which involves rotation of the lower haul rope return sheaves (block and tackle principle). This feature is a key component of a line evacuation system based on carrier recovery and passenger return to the stations under all foreseeable fault conditions. It is also possible to impart movement to the rope loops without moving the cars. To move the upper loop, which is not powered by the drive, the two superimposed return sheaves on the car are connected so that the lower rope loop return sheave (driven by the lower rope loop) turns the upper rope loop return sheave and thus imparts movement to the upper rope loop. That greatly simplifies haul rope inspection and maintenance.

THE WORLD'S FIRST CABRIOLET CABIN

Whereas passengers cannot see the Cabrio-Bahn's various innovative rope setup details, they definitely appreciate the fascinating design solution adopted with the open-top cabin, although here again it is not so much the engineering that counts as the striking principle of a cabriolet and the elegant lines, which were among Gangloff's trump cards in the tendering procedure. The clean lines and the elegant metallic white finish are a perfect match to this futuristic installation. And in addition to the open top deck, the generous use of glazing ensures that all passengers can enjoy unrestricted views of the surrounding mountains. Compared with conventional jigback cars, the cabriolet cabins are a completely new product in terms of looks and engineering developed by Gangloff. For that reason we are devoting a separate article to this outstanding carrier on page 58 of this edition of ISR.

Josef Nejez

TECHNICAL DATA

Stanserhorn Cabrio-Bahn
2-car jigback, new ropeway system with Funifor-style rope configuration

Elevation at bottom station	714 m
Elevation at top station	1,898 m
Line length	2,319 m
Vertical difference	1,184 m
Number of towers	4
Diameter of track rope	4 x 66 mm
Track rope gage	5.00 m
Diameter of upper haul rope	30 mm
Diameter of lower haul rope	26 mm
Drive	bottom station
Max. continuous output	919 kW
Max. start output	994 kW
Carrier capacity	60 pers.
Max. line speed	8.0 m/s
Min. transit time	6.5 min
System capacity	465 P/h

Contractors

Ropeway engineering	Garaventa
Electrical engineering	Frey AG Stans
Cars	Gangloff
Haul rope	Fatzer
Top deck access control system	Bilexa

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The open-top cabin for the Cabrio-Bahn

GANGLOFF In terms of design and structural engineering, the double decker cabriolet cars for the Cabrio-Bahn were a challenging experience for the Gangloff engineers.

Compared with other ropeway construction projects, the design of the cabins played an extremely important role in the sales negotiations and was doubtless the critical factor in the decision to award the contract for the cabins for the Stanserhorn Cabrio-Bahn to the Swiss Gangloff company.

The double-decker concept with an open top deck called for new solutions with regard to the use of space and passenger movements. The interior of the lower deck is dominated by a central spiral staircase, which was designed to ensure that

- the stairs are not too wide so that passengers can hold tight on both sides so as to reduce the risk of accidents,
- the staircase is not too steep for convenient use, and
- the diameter is not so large that there is not enough space on the lower deck for the free movement of wheelchairs.

Underneath the staircase, space was found to accommodate some of the electrical controls, and the cabin attendant's stand is also at the foot of the staircase.

STRUCTURAL ENGINEERING

The innovative system of a wide-gage reversible ropeway with the carriers traveling between and on a level with the twin track ropes makes completely new demands of the supporting structure for the cabins. The Cabrio-Bahn cars are also fitted with a self-regulating hydraulic system that keeps the floors level regardless of load conditions and external forces. The calculations therefore had to take account of load cases that are not otherwise encountered on a jigback, and that played a significant role in the design of the supporting structure.

Jigback cabins of this size normally incorporate suspension rods to handle the vertical forces. In this case that was not possible because they would have formed an obstacle to passenger movements to the left and right of the staircase. In addition, one of the points at which the cabin is supported by the carriage frame is located immediately above the door to the lower deck. The supporting structure – a completely lightweight alloy design – was accordingly incorporated in the floor frame for the top deck, with two sturdy cross-members connecting the cabin suspension points plus two longitudinal side members. The floor of the top deck rests on a radial assembly of auxiliary members.

The white plastic cladding of the

PHOTO: STANSERHORNBAHN

sidewalls conceals members made of welded bent steel plate, which connect the supporting frame with the floor of the lower deck. These members are the equivalent of the suspension rods in a more conventional design.
The lower deck floor frame is more or less a conventional assembly using aluminum extrusions. It also carries the attachment points for the underfloor equipment.

EXTERNAL SKIN

The external skin of the cars is mainly glass. For reasons of weight, it was not possible to employ tinted glass at the level of the intermediate deck. Instead, painted metal panels were used, with GRP elements (glass-reinforced plastic) at front and rear and for the corners. The glazing takes the form of convex and double convex laminated glass panels glued to the supporting structure.
The white cladding for the external frame and floor is also GRP. These parts have a purely aesthetic role without any load-bearing function. In order to be able to incorporate a sliding door with the required clearance, the external frame had to be divided into two in the area of the door; one part is attached to the door and moves with the door as it opens and closes. This solution was adopted for the design effect with the door closed and for the required clearance with the door open at the same time.
The underfloor systems enclosure is comprised of permanently mounted corner elements with intermediate covers that can be quickly opened or even completely removed for inspections and maintenance. At the center of the enclosure, underneath the spiral staircase, the engineers have located the piston accumulator and gas bottles for the hydraulic system, with the electrical cabinet with the batteries, battery charger and power electronics on the uphill side and the hydraulics for the self-leveling system on the downhill side.

TOP DECK

The top deck is made of impervious steel roof sheeting. It is slightly higher in the middle so that any water on the roof runs away from the spiral staircase and flows into the surrounding gutter. Wooden planking is used for the floor. There is an air gap between the planks and the steel roof as well as spacing between the individual planks. That permits the rain to drain between the planks onto the roof and from there into the gutter. It is also an elegant solution in terms of looks. For design reasons, the steps are also made of wood.
To facilitate shipping, the balustrade round the top deck is detachable. It comprises laminated glass panes glued to a light supporting railing for an optical match with the lower deck.
The staircase is located in a one-meter high cylinder, with one quarter cut away for access. On the top of the cylinder there is a two-piece watertight cover, with a moving panel that slides over the fixed section to open and close the staircase. This solution makes it easy for the cabin attendant to close the staircase in wet conditions. Under the staircase there is a simple control cubicle for out-of-service operations and the loudspeakers for announcements to passengers on the top deck. Video cameras enable the cabin attendant to monitor the situation on the top deck from the control cubicle on the lower deck.

ACCESS CONTROL

The cabin is designed to carry sixty passengers, with a maximum of thirty on the top deck. Carrier loading is via the lower deck. At the bottom of the staircase leading to the top deck is a Bilexa turnstile, which keeps a count of the number of passengers on the top deck, with the number of available places clearly displayed, and locks automatically when the maximum of thirty is reached. Unloading in the stations is from both decks simultaneously. The top deck has an electric sliding door on one side for that purpose.
The cabriolet car is a masterpiece of engineering. Congratulations to all concerned!

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On course for growth

BARTHOLET In the context of its strategic planning, BMF Bartholet Maschinenbau AG is establishing three European subsidiaries this year.

Bartholet has taken this key decision so as to guarantee more direct customer contact and faster service. The new subsidiaries in France, Germany and Poland represent a further chapter in the success story at Bartholet Maschinenbau AG. With these additional locations, the successful Swiss ropeway manufacturer is signaling confidence in its ability to maintain a policy of further expansion.

BMF FRANCE

The contract for BMF France was signed in April at this year's SAM winter sport trade show in Grenoble. The company has found an ideal location for its French subsidiary in the Alpespace industrial park in Montmélian. With the new location, BMF has strengthened its presence on the French ropeway market and will be able to create new jobs in the region in the medium term.

50TH ANNIVERSARY

As one of the world's leading companies in the field of ropeways and leisure park installations, Bartholet Maschinenbau AG this year celebrates its 50th anniversary. The big event will be held at the company's Swiss headquarters in Flums at the end of June, and the ropeway manufacturer is expected to mark the occasion with a number of innovations and further highlights.

FULL ORDER BOOKS AT BMF

In 2012 BMF is due to commission a second detachable 6-seater chairlift in Val d'Isère, France. The fact that the contract was again awarded to the Swiss ropeway manufacturer is doubtless a reflection of the customer's satisfaction with the existing BMF installation. That comes after the construction of two other BMF installations in France, in Les Arcs. Again, that is an expression of the trust placed in the Swiss company.

A number of other continuously circulating systems are now in the planning stage for BMF's domestic market in Switzerland, including a detachable 6-pack with the latest innovative chairs for the famous ski area in Laax, a telemix (or chondola) combining chairs and gondolas within the same system for La Berra in Canton Fribourg, and a gondola to be built in Saas-Fee in Canton Valais in 2013 as a big three-stage installation with 10-seater cabins.

In addition, the company is busy with projects on other markets this year, including Italy, Poland and Turkey. That includes BMF's first detachable installation to be sold to Italy (Passo Tonale). Other detachable 6-seater chairlifts in Zloty-Gron and Poniwiec in Poland are further items in the full order books at Bartholet Maschinenbau AG. And the com-

PHOTO: BARTHOLET

pany is also moving into another new market with one detachable and one fixed-grip chairlift for Turkey.

INSTALLATION OF A JIGBACK IN LEUKERBAD, SWITZERLAND

Work on the new Leukerbad - Gemmi Pass jigback in Canton Valais continues until the end of June. This is a complete rebuild, which the operator is marketing with a focus on the improved quality of the ride. The new Gemmibahn has double track ropes and the latest drive engineering and safety features. The new cabins can carry 35 passengers each, and the system has a design capacity of 335 pers/h.The new jigback is due to go into service on 1 July 2012. This is a further project in the field of reversible tramways for BMF following the 60-passenger jigback built in Moléson in Canton Fribourg and last year's commissioning of the company's first ever Funitel in Val Thorens, all of which clearly establishes the Swiss company's credentials in reversible tramway engineering.

A Spanish delegation at the BMF booth at SAM in Grenoble

New attraction

NEVEPLAST On May 7th a new attraction for the public was opened at the Safari Park in Pombia (Italy).

In the framework of its strategic planning, the Safari Park management were looking for an exciting attraction that would be economical in terms of initial and running costs and would also be in keeping with the park's environment-friendly philosophy. The decision was accordingly taken to replace the old slalom slides with a more modern product. The solution proposed by the Neveplast planning office was to modify the existing structure and replace the obsolete slides with 40-meter-long Tubby tracks. The actual work on the site did not take very long, just five days to adapt the main structure and two to assemble the Tubby tracks. With their focus on the natural environment, the management decided to order blue tracks and to call the new attraction the Zambesi Boat. That is a reminder of the great river that crosses the land where many of the animals in the Safari Park were born and also of the amazing Victoria Falls, which are almost recreated in the Tubby snowtubing experience. Even the scenery for the ride is a product of the same philosophy, with timber used as an integral component of the entire structure. The result is new life breathed into an old facility on a highly cost-effective basis.

PHOTOS: BARTHOLET, NEVEPLAST

New attraction for the Safari Park in Pombia

TECHNICAL DATA

of the structure

Height	7 m
Length	40 m
Dimensions	6.5 x 45 m
Hourly capacity	500 runs

First appearance with a new identity

MYNEIGE The manufacturer of snowmaking systems mYNeige (formerly Johnson Controls Neige), which is based in France, made its first appearance with its new identity at two major international mountain resort events in 2012, namely Alpitec / Prowinter trade show in Bolzano (Italy) and SAM in Grenoble (France).

From the left: The top two at mYNeige: President Arno Inauen and Director-General Régis-Antoine Decolasse

This year's SAM in Grenoble provided a fine opportunity to see the new releases that mYNeige will be offering in the coming months.

In addition to the usual purpose of these industry events – presentation of new products, relationship building with customers, etc. – these two trade shows allowed the mYNeige team to take the pulse of its customers and the market with regard to both the new identity and the company's position following acquisition of the snow business of Johnson Controls by TechnoAlpin, and mYNeige was gratified to note a very positive perception of the recent changes affecting the company.

To strengthen communications relating to mYNeige, a press conference was held at the company's stand at SAM, which gave the industry a fine opportunity to meet Arno Inauen, the new President of mYNeige, and Regis-Antoine Decolasse, who has been appointed Director General of the company.

During the conference, the two gentlemen presented the business strategy for the coming months: organizational evolution, market orientation and a strategic products and services offering. Probably the strongest message delivered by the two speakers relates to the autonomy that mYNeige enjoys, which can be summarized in the phrase "One group, two entities".

In short, no changes have been made to the teams in place, and the current product lines also remain the same at mYNeige. Of course, synergies will be implemented between the two entities, especially in terms of procurement but also with regard to research and development.

mYNeige remains a fully committed player for ski area operators and will continue to support and optimize its installed base of snowmaking products and systems (around 370 installations worldwide, with some 45,000 snow guns in operation and 1000 machine rooms). In addition to its current well established partnerships, mYNeige will also pursue a strategy of strong growth in exports, principally to Eastern Europe and Asia but also in North America.

NEW RELEASES BY MYNEIGE

The two trade shows, Alpitec and SAM, provided an opportunity to unveil the latest releases that mYNeige will be offering in the coming months, including a redesigned version of the Mobilys series of mobile standalone snow guns, which generated keen interest among the ski area operators who visited the manufacturer's stand. The Mobilys for the 2012/2013 season will be available with a 10-meter version of the Rubis Evolution, which will offer improved output over the initial version of the Mobilys MRA6, which was equipped with a 6-meter Rubis Evolution.

Another attraction for operators of mYNeige snowmaking installations was the mobility and remote control solutions presented at the SAM trade show. Remote monitoring on a rugged laptop for working in extreme winter conditions, and schematic trail views and snow gun controls in the form of apps for iPad and other smartphones are just some of the solutions that will be made available to mYNeige customers in the coming months.

Design and new technologies: With these innovations, mYNeige intends to send out a strong signal to the market and to focus more than ever on its activities in R&D and innovation-based enhancements.

PHOTOS: MY NEIGE, C. AMTMANN

Oscillations in ropeways

Structural oscillations deriving from the moving rope/sheave system: elimination of the exciter or reduction of the intensity of the oscillation
Part 4

Dipl.-Ing. (ETH) Georg A. KOPANAKIS
Consultant for ropes and ropeways

Once the exciter of the structural oscillation has been identified (see part 3, ISR 1/2012, p. 48), the next step is to consider the measures that can be taken to tackle the cause and eliminate the exciter. If this should prove to be impracticable, which is usually the case, the alternative will be to find ways and means of reducing the intensity of the oscillation to a point where no significant problems are caused, i.e no noise, no reduction in the quality of the ride, and no excessive loads imposed with resulting damage to structural components, etc. (see also part 1, "Solutions to oscillation problems", ISR 6/2011, p. 50).
In this article, ways are presented of assessing the "potential exciter" as discussed in part 2 (ISR 1/2012, pp. 46-47) to see whether it can be eliminated or at least modified so as to mitigate its effects.

COUNTERMEASURES AGAINST OSCILLATIONS DERIVING FROM THE ROPE/SHEAVE SUBSYSTEM

Strand-induced: In this case the exciter is the rope/sheave system, and elimination of the exciter would require the use of an alternative rope deflection and/or rope guiding system, which would logically completely eliminate the exciter. At the present time, however, the author is not familiar with any alternatives capable of fulfilling all the functions of today's rope/sheave system, so that this approach to solving the problem can be discounted in this context.
In this article, only those potential solutions are discussed in which the oscillations are eliminated or at least reduced by modifying one of the system components (rope or sheave) or by modifying or adjusting both components

■ Modifications to the rope: Theoretically, the simplest change to the rope in order to eliminate the exciter would be to use a rope that is completely circular on section. Since the moving rope must have a high degree of flexibility, however, and in most cases must permit splicing, there is no alternative to the stranded rope. That makes it difficult to meet the ideal goal of a rope with a completely circular cross-section.
On the other hand, by using a stranded rope with more than the six strands that are typical today (e.g. seven or eight strands), it is possible to reduce the amplitude of the oscillation. In that case it can be expected that the intensity of the oscillation will also decrease.
This is not always the case, however, because an increase in the number of strands also increases the frequency of the exciter (in proportion to the number of strands). Should the new exciter frequency happen to coincide with the natural frequency of the oscillator, the intensity of the resulting oscillation will actually be increased (see also part 1, "Free and forced oscillations and natural frequency", ISR 6/2011, p. 49). This has been confirmed on a real-life installation: Following the replacement of a 6-strand rope with an 8-strand rope on a continuously circulating ropeway (detachable quad chairlift with a 43 mm rope running at a maximum speed of 4.0 m/s), oscillation intensity was lower on the towers that had originally been subject to pronounced oscillation. At the same time, however, other towers, where there had been no problematical oscillations with the 6-strand rope, were affected by strong vibrations following the change-over to the 8-strand rope. It is therefore clear that the use of a 7- or 8-strand rope alone cannot be the solution in the fight against excessive vibrations.
With the products available on the market today, the use of a stranded rope in which the strands are triangular in shape is problematical for all ropes that need to be spliced, as a 6-strand rope with triangular strands cannot be spliced. In theory, splicing would be possible with a 7-strand rope, but it would not be possible to reach today's standards in terms of constant diameter and fatigue strength.
The stranded rope that comes nearest to satisfying the goal of a rope that is circular on section is the Performa manufactured by Fatzer AG. On this rope the round section – in combination with all the advantages of a round strand rope – is achieved by inserting extruded plastic filler profiles between the adjoining strands. This creates a rope surface that comes very close to the theoretical cylindrical shape of the rope.

■ Modifications to the sheave: The amplitude of the oscillation can be significantly influenced through an appropriate choice of sheave diameter, and shape and depth of the groove. With regard to sheave diameter it can be said: The larger the diameter, the smaller the amplitude of the oscillation (Figure 1).
This means that when the diameter of the rope is increased, the diameter of the sheave must also be increased. Since the mass of the sheave has an influence on both sheave handling and inertia, however, there are

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limits to any increase in diameter. The combination of this limitation and bigger rope diameters on installations built in the last few decades has resulted in smaller relationships Dsheave /drope. Whereas typical continuously circulating ropeways had a Dsheave /drope relationship of about 9.3 to 9.7 in the 1970s, the figure today is approx. 7.5 to 8.6, a reduction of between 12 and 20 percent.

Geometry of the groove: If it were possible for the rope to run over the sheave with at least two strands in constant contact with the groove, the amplitude of oscillation would theoretically be zero (Figure 2), but this can only be achieved if the groove is of a suitable shape and depth.

Groove depth: Figure 2 shows the cross-section of a rope running over a sheave. The position of the rope relative to the groove of the sheave on passage over the sheave can be illustrated with the rope cross-section rotating around its axis in the groove. When the rope passes over the sheave by a lay length, the position of the strands relative to the groove of the sheave corresponds to that of the strands in the cross-section when the rope section is rotated once around its own axis in the groove (Figures 3a, 3b).

This shows that, in the case of a 6-strand rope, the above condition (at least two strands in continuous contact with the groove) can only be satisfied where the radius of the groove matches the radius of the rope and the groove offers at least a 120° angle of wrap, i.e. groove depth is at least 25 percent of rope diameter (Figure 4).

If both these requirements were met in full, however, the ends of the grip jaws would collide with the sheave. It would also lead to increased transverse acceleration, as seen in practice. As is so often the case in life in general and in engineering in particular, what is needed is the right compromise.

- Modifications to the rope/sheave system (adjustments to both components):

Providing that the rope is in constant contact with the sheave, i.e. as long as rope speed is low and there are no dynamic effects, one can try to adjust the relationship between effective sheave spacing (Figure 5) and strand spacing so that when one sheave of a two-sheave frame is in contact with a strand peak, the next sheave is in contact with a strand valley (Figure 6).

As a result, movement at the fulcrum of the frame is reduced – to zero in the ideal case – and the amplitude of the oscillation transmitted to the next larger frame is also reduced, also to zero in the ideal case. Depending on the design of the two-sheave frame, the relationship thus obtained will often be 9.5 or 10.5 or 11.5. What is important in this context is that the relationship (for a 6-strand rope) should not be close to 12 (i.e. not 11.5 or 12.5) because of the danger of the effects of strand-induced vibration being compounded by potential waviness in the rope.

This measure (adjusting the relationship between effective sheave spacing and strand spacing) can only be a suitable tool for reducing strand-induced vibrations, however, if the following conditions are met:

- The relationship has been set correctly.
- The design geometry of the sheave batteries employed by the ropeway engineering company is identical with the as-built values.
- The design lay length of the rope matches the finished product.
- The geometry of the rope as delivered is not modified while pulling in the rope.
- No twist is imparted to the rope during ropeway operation resulting in changes to the rope's design geometry.
- No dynamic processes are triggered at ropeway operating speed, and the sheave remains in constant contact with the contours of the rope.

The state of equilibrium achieved with such difficulty as described above is fragile. Take the case of a 6-strand rope with a diameter of 50 mm, a lay length of 360 mm and effective sheave spacing of 630 mm and thus an optimum relationship between effective sheave spacing and strand spacing of 10.5: At 3 percent elongation in lay length, the optimum relationship of 10.5 deteriorates to a poor 10.19, and at 3 percent shortening to an equally poor 10.83. As every ropeway insider knows,

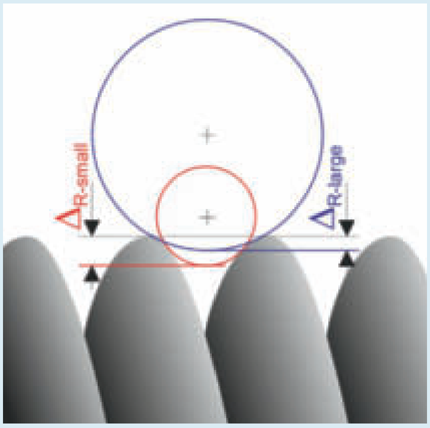

Fig. 1: Influence of sheave radius on the amplitude of the exciter

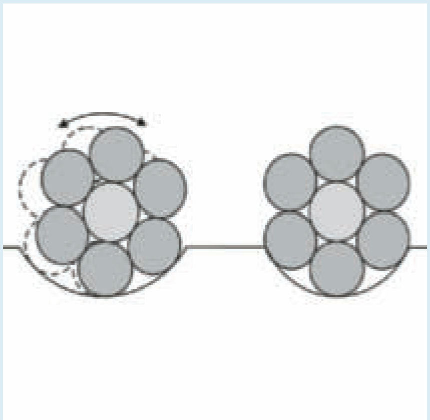

Fig. 2: Influence of groove geometry

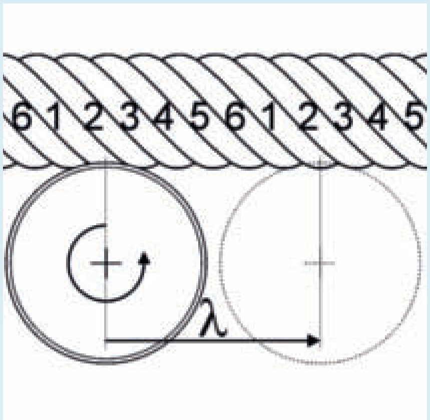

Fig. 3a: When the rope passes over a sheave, strand behavior ...

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such changes are not unrealistic; on the contrary, they are common figures for changes in lay length under typical operating conditions.
For that reason it makes no sense simply to focus and rely on the relationship between effective sheave spacing and strand spacing. The desired results can only be achieved with a combination of all the above-mentioned measures (sheave size, shape and depth of the groove, and a match between effective sheave spacing and strand spacing). The necessary precautions must also be taken in the construction and operation of the ropeway (professional team for drawing in the rope, regular inspections for wear on rope guiding components, correct alignment of sheave batteries, and minimum fleet angle on the sheaves, especially following maintenance and repair work, etc.) to ensure that the relationship between effective sheave spacing and strand spacing as specified by the rope and ropeway manufacturers remains unchanged. The potential extent of a resulting fault is illustrated in Figure 7.
Nevertheless it must be remembered that, with regard to rope guidance, and despite the above mentioned (and usually effective) measures, there will always be a residual intensity of oscillation in the various frequencies. That means vibration problems can still occur where exciter frequency coincides with the natural frequency of a structural component. Assuming that a reduction in rope speed would be unacceptable in terms of operating requirements, such cases can only be handled by making changes to the mass or stiffness of the structural component involved so as to reduce the amplitude of the oscillation (Figure 8).
This conclusion calls for a comment on the fatigue-resistant design of all structures subjected to such oscillations:
Although the need for adequate fatigue strength is generally accepted, it must be pointed out that the effective implementation of a fatigue-resistant design is not an easy matter, all the more so as the factors on which the calculations need to be based are hard and in some cases impossible to quantify.
Lay length-induced: Here again the exciter is the rope/sheave system, but this time in combination with waviness in the rope. Elimination of the exciter is not difficult in this case insofar as rope waviness is not a normal condition; a rope simply should not be wavy, and the problem can be solved by replacing the wavy rope with a rope that does not have that defect.
Here again, however, things are not always as simple as that. As already explained in both this and the previous article, an oscillation is primarily the product of the frequency of the exciter and the natural frequency of the oscillator, i.e. it is possible for even a minor degree of waviness in the rope to cause oscillation problems. This is an important point because no satisfactory answer has been found to the question of permissible waviness tolerance; the codes merely define maximum values for waviness as measured during the manufacturing process. On the other hand, practical experience shows that ex-works waviness over the full length of a rope will almost certainly increase under operating conditions! In other words, a rope with a degree of waviness that was initially within the prescribed tolerance will exceed the tolerance limits after a certain period of operation. In this context, a meaningful procedure acceptable to all parties (rope and ropeway manufacturers and operators) for measuring critical waviness in the rope would help to avoid future misunderstandings.
It should be mentioned that this discussion is not relevant in the case of localized waviness in the area of an imperfect splice. In such cases the waviness can often be corrected by carefully re-splicing the rope.

SOLUTIONS TO OSCILLATIONS DERIVING FROM ECCENTRICITY OR POLYGONALITY IN A SHEAVE

In this case the exciter is the out-of-round or polygonal sheave. Elimination of the problem is again simple, as one merely needs to replace the defective component. Most frequently, eccentric running in a sheave is the result of out-of-roundness in the liner, and the problem

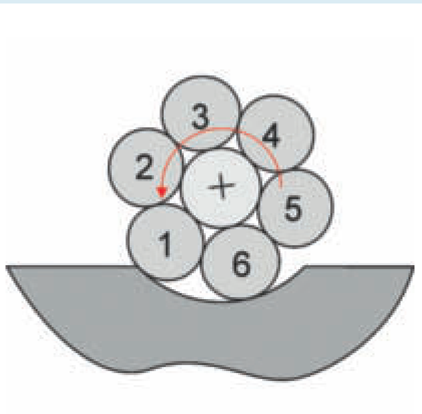

Fig. 3b: ... is identical with the case of rotation of the rope section in a groove.

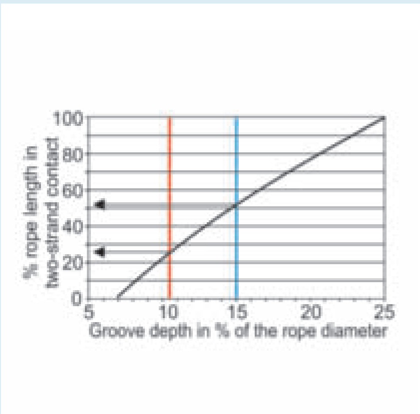

Fig. 4: Influence of groove depth: Share of rope length with two strands in contact with the groove at a given groove depth

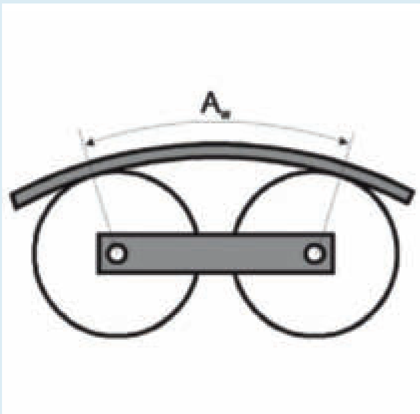

Fig. 5: Effective sheave spacing: length of rope between the contact points of the rope with the two sheaves of a balance

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can be solved by replacing the liner. In the rare case that eccentricity is the result of a defect in the sheave itself, it will naturally be necessary to repair or replace it in order to eliminate the excitement. That also applies where the problem is caused by a polygonal sheave.

SOLUTIONS TO OSCILLATIONS DERIVING FROM OTHER CAUSES

Grip passage over a compression tower: Elimination of this non-periodic exciter while taking account of the above-mentioned need for a groove of an appropriate geometry and depth would logically necessitate the use of a grip where the ends of the jaws cannot collide with the sheave. As such a solution has not yet been found, the answer will once more be to seek a compromise.

Grip passage under a depression tower: Elimination of this non-periodic exciter would theoretically involve re-designing the sheave train and/or grip, but no adequate solution to the problem is available. The response must therefore be to reduce the amplitude of the oscillation by optimizing the shape of the approach sleeves. This also means that the condition of the approach sleeves is critical for avoiding vibrations at this point on the installation.

Simultaneous passage of two grips: The exciter of the resulting rotational oscillation is the moment produced on passage of the grips between the rope and the sheaves when two grips pass under the sheave trains on both sides of the tower at the same time.

This exciter can be non-periodic but if the arrival of the grips at the sheaves is periodic, the exciter will also be periodic. The solution would be either to eliminate the impact of grip passage or to avoid the simultaneous arrival of the grips at the sheaves on both sides of the tower. Since the former solution is not possible, as stated above, measures must be taken to prevent simultaneous arrival of the grips at the sheaves. That involves adjusting the carrier interval.

Should that not be possible for any reason, the only way to avoid pronounced rotational oscillations and the consequent risk of deropement would be to modify the tower structure to ensure that the natural frequency of rotation of the tower head does not coincide with the frequency of the excitement.

Start-up resistance: The exciter of this rotational oscillation of the tower head is the start-up resistance of the sheaves of the two sheave trains on a tower, which produces a torsional moment. This is a form of non-periodic excitement that is only very rarely critical. Such oscillations can be avoided or at least minimized by focusing on the rolling resistance of the sheave bearings and the condition of the sheave liners.

The subject in the next of this series of articles on “Oscillations in ropeways” will be oscillations in rope spans. As in the case of structural oscillations, the causes of such oscillations will be considered first (e.g. changes in forces, wind, rope/sheave subsystem, etc.) and then the best ways of eliminating or at least reducing the effects of such oscillations.

Georg A. Kopanakis

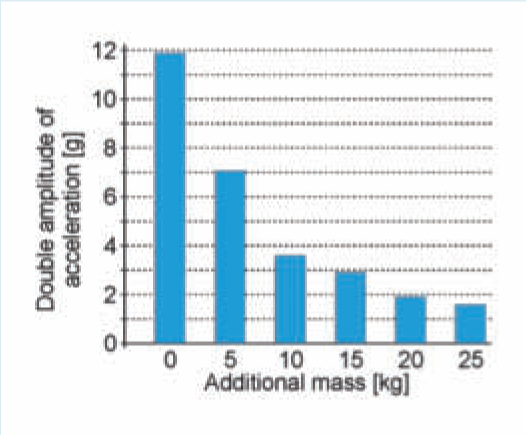

Fig. 8: Influence of an additional mass on the oscillation amplitude of a platform

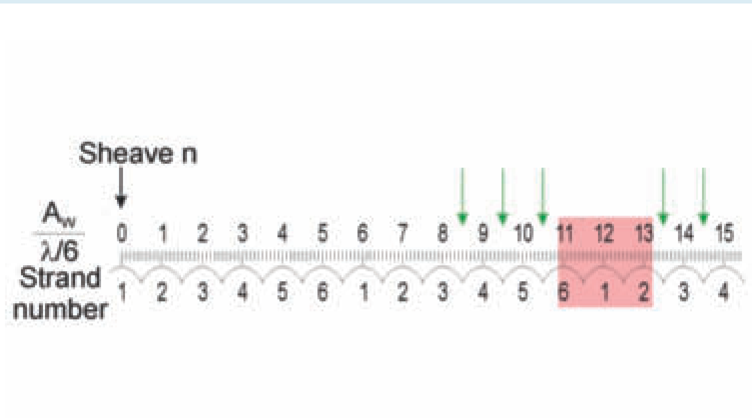

Fig. 6: When the first sheave is in contact with strand peak no. 1, the second sheave should be in contact with one of the strand valleys indicated by the green arrows.

Fig. 7: Change of lay length before and after a carrier grip caused by incorrectly aligned rope guiding elements

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