



J.C. Weis and I.M.L. Ridge  
*W.A.J. Albert and his wire rope*

ODN 0834

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It is generally accepted that by careful attention to detail and employing the strength of iron wire, that the first serviceable wire rope used in a technical application was produced in 1834 by Wilhelm August Julius Albert.

Albert's rope was developed for lifting ore out of the "Caroline" shaft near Clausthal. Since 1834 wire rope has developed in many ways: Today there are hundreds of different constructions and in contrast to Albert's ropes which had a diameter of approximately 18 mm and length up to 605 m; ropes of 140 mm diameter have been manufactured as well as ropes over 3,000 m in length. In addition to its use in applications like mine shafts wire rope is now an integral part of modern life, and is found in many applications e.g. cranes, elevators, ropeways, bridges, architectural buildings to name but a few.

In the paper the authors provide a summary of the work around W.A.J. Albert's famous rope which we honour this year in its 175<sup>th</sup> anniversary.

K.-H. Wehking  
*State-of-the-art and future development of research and science of rope technology at the Institute of Mechanical Handling and Logistics at the University of Stuttgart*

ODN 0835

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Questions of Rope Technology, which means questions of the development, research and science of ropes is one of the three working fields of the Institute of Mechanical Handling and Logistics. The Institute was founded in 1927 and the first Director of the Institute, Prof. Woernle, started at that time with systematic bending tests on wire ropes. From 1927 up to now the special field of rope technology was throughout supervised by a professor of the Institute.

Today, the Institute has about 70 employees (25 student workers, 45 full-time employees) and more than one third of the staff are working in the field of rope

technology. The paper outlines the state-of-the-art and the new fields in rope technology which Stuttgart University are working on at the moment and will work on in the near future.

M.J. Cotte

ODN 0836

47

*The invention of the cable made of numerous thin iron wires, Marc Seguin & Co, 1821-1825*

The Seguin's Brothers Company were responsible for the invention of the cable made of numerous thin iron wires (diameter from 2 to 3 mm) in the context of the first suspension bridge proposed over the Rhone River, France, in the early 19<sup>th</sup> Century. It was one of the most difficult rivers in Western Europe for bridge construction by classical means of masonry arches. No permanent bridge had been built there from the end of the Middle Ages.

The design and application of iron wire cable for a major bridge (two spans of 85 m) was accomplished between the end of 1821 (start of the project) and the summer of 1825 (the Tournon-Tain suspension bridge).

An exceptional archive source coming from the enterprises of Seguin's brother, in *Archives départementales de l'Ardèche*, Privas, France, allows a deep study of this invention and its application to a major suspension bridge. Origins of the idea and its implementation were complex, but different roots must be surely identified: adaptation and evolution of foreign ideas, local craftsman culture, economical and socio-technical analysis, and the relationship between experimental science and technology. The wholeness bears us a remarkable case study in technical innovation.

G.F.D. St. Germain

ODN 0837

59

*High performance synthetic roundslings*

From the invention of wire rope by W.A.J. Albert in 1834 to 1987 there was no better alternative for heavy lift tension members. Wire rope slings replaced heavier natural fibre cordage and chain slings. In 1987 the first high performance synthetic fibre was used in the construction of roundslings that were competent to lift heavy loads. The invention of aramid fibres by DuPont in the 1960's and subsequent commercialism provided the resource to improve tension members by lowering their weight in a significant manner. The advances in these products over the last twenty years have led to the replacement of wire rope slings in many applications.

A. Carbogno, S. Mateja and W. Raszka

ODN 0838

73

*Tensile fatigue examination of flat rubber-coated tail steel ropes of SAG type*

Flat rubber-coated tail steel ropes have been fabricated since 1989 by the Manufacturing Company for Rubber-Coated Steel Ropes SAG, located in Katowice, Poland. To date, 442 units of such ropes have been delivered to customers altogether. The ropes are operated in shafts of domestic collieries with their depth up to 1,100 m as well as in foreign ones that are as deep as nearly 1,500 m. The total weight of a single, freely suspended rope can sometimes reach even 29,000 kgf. Operation intensity of hoisting machinery depends on shaft depth and can be sometimes as high as 600 cycles per

day. Under such operating conditions in the Polish mining industry, the lifetime of SAG ropes ranges from 9 to 15 years with the total number of cycles from 1.4 to 2.75 million.

The paper presents progression and results of fatigue examinations on Polish flat rubber-coated tail ropes of SAG type. The tests under vertical (tensile) elongating loads were carried out in the Research and Supervisory Centre of Underground Mining Co. Ltd. (CBiDGP) with use of the fatigue test machine UPDh-I00S. The examined samples of SAG ropes were able to withstand, an average value of  $N_{SR} = 2,148,000$  cycles until fatigue failure.

B. Poursadian

ODN 0839

89

*Some recent innovations for production of high-strength and fatigue-resistant 3-strand and 4-strand wire ropes*

On this 175<sup>th</sup> anniversary of Albert's first 3-strand wire rope, it is fitting to present some recent innovations in the design and manufacture of 3-strand and 4-strand wire ropes. This paper will present the results of a novel method of manufacturing a 3-strand rope from AISI Type 304 stainless-steel wires. This method manipulates the state of residual stresses in the cold-drawn stainless-steel wires to achieve an increased level of fracture toughness and in turn yielding a rope with higher strength and endurance. The actual residual stresses present in the wires at different stages of manufacturing were measured using the X-ray diffraction technique. The measured values of residual stress are reported showing that the state of residual stress present in the cold-drawn wires can be changed from an undesirable tensile state to a very desirable compressive state. The highest tensile residual stress in the mid-section of a 1.1 mm wire was 369 MPa. The tensile residual stress at the mid-section was decreased to 77.9 MPa while a compressive residual stress of 209 MPa was imparted on the outer surface of the wires. The 12.7 mm 3×36 WS wire ropes containing the above mentioned thermally and mechanically stress relieved wires were subsequently tensile tested showing that the strength-to-weight ratio for the rope produced with the novel method was 20% higher than that of a rope of the same diameter produced with the standard method. The reverse-bend-fatigue cycles to failure were also increased by 65% for the rope made with the novel method. A comparison of fracture toughness of the wires is made indicating that the novel method increased the fracture toughness of the individual wires. SEM photographs of fractured ends of wires will be presented as well as the results of the X-ray diffraction method of residual stress measurement. Several applications in which the above described novel ropes have been successfully used will be described.

P.J.H.M. Smeets, M.P. Vlasblom and J.C. Weis

ODN 0840

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*Latest improvements on HMPE rope design for steel wire rope applications*

In the last few decades, high performance synthetic fibres have increasingly substituted steel wire ropes in many applications. One class of high performance synthetic fibres are the so-called High Modulus Polyethylene (HMPE) fibres. In the mean time this fibre is employed in all kind of applications where strength, weight, endurance and protection come into play. Present applications are in personal protection, technical textile products, medical applications, sports goods and last but not least in the rope industry. Starting with smaller diameter ropes in sports, over the last 25 years HMPE based ropes

have been introduced in industrial environments such as harbour towing, ship and rig mooring, commercial fishing, forestry and electrical cable pulling. Due to further performance improvements in recent years also “running” wire rope industries like deep-sea installation, space tethers, cranes and mining have shown interest in the advantages of light-weight, equal strength to diameter ropes based on HMPE fibres to improve or replace steel wire ropes.

In this paper the latest developments in research and development are presented for ropes with HMPE fibres showing that important design parameters can match or exceed steel wire rope properties especially where high payloads together with long rope length are necessary.

W. Vogel and W. Scheunemann

ODN 0841

115

*The use of small steel wire ropes in traction sheave elevators*

Higher, faster, further or, as the trend in the elevator construction business goes: smaller, thinner and lighter. Growing pressure on costs and a tougher competitive environment have led variously to technical solutions that are shaped solely by cost optimisation parameters. Yet amid all these cost-capping discussions, we should never ignore safety and reliability requirements - especially with traction sheave elevators which are of such safety-related and public-interest concern.

The machine element steel wire rope is the core element in any elevator system, affecting performance characteristics and system costs. Smaller ropes, with the same diameter ratio of traction sheave to steel wire rope,  $D/d$ , lead to smaller guide sheaves and smaller drive units with lower (cost determining) output torques. However, smaller sheave diameters also permit smaller installation space and, consequently, reduced head room. Larger cabin floor areas are possible. But what about safety-related requirements when the steel wire rope is running, which are: service life and the point of wire rope discard?

At Interlift 2007, Pfeifer DRAKO Drahtseilwerk GmbH presented small steel wire ropes from the STX series with nominal diameters of  $d = 4$  mm and  $d = 5$  mm that have been issued with product type test certificates by TÜV Süd, Germany. This certification applies to elevator systems using traction sheaves with V-grooves of  $\gamma = 40^\circ$  to  $\gamma = 50^\circ$  and guide sheaves with round grooves and a diameter ratio  $D/d = 40$ . In a further development, however, and for the above-mentioned reasons of cost, space requirement and useable cabin floor area, the sheave diameter ratios were reduced to  $D/d = 30$ . The following paper is a report about extensive development work on small steel wire ropes with rope diameter  $d = 4$  mm, ropes deployed with V-grooves ( $D/d = 40$ ) and guide sheaves ( $D/d = 30$ ). Our development work always reflects “system thinking” - which means de facto that the rope manufacturer no longer delivers just the rope but additionally provides the elevator manufacturer and/or the distributor with a components and methods service in order to make these advanced and future-ready small steel wire ropes a safer and reliable system element.

P. Dietz, A. Lohrengel, T. Schwarzer and M. Wächter

ODN 0842

125

*Problems related to the design of multi-layer drums for synthetic and hybrid ropes*

Rope drum and rope – as parts of a hoisting system, must constantly be improved and modified concerning increasing requirements. To fulfil the requirement of a further weight reduction of the system, high strength chemical-fibre (man-made fibre) ropes or compound constructions, so called hybrids, shall be used in the future in multi-layer winding on the drum. Their rope characteristics, that are different from those of common ropes, cause an entirely different drum load, which urgently requires an adaptation of the existing calculation bases to the new rope types.

This paper shall give a review on current projects on designing and dimensioning rope drums with a multi-layer winding with synthetic or hybrid ropes and gives an outlook on further required steps to the adaptation of the calculation processes.

O. Gronau and G. Steinbach

ODN 0843

139

*Dimensioning of rope drives and operating time of wire ropes*

The purpose of the dimensioning of rope drives is, by application-specific interactions of safety factors and diameters of the rope drive elements, to ensure sufficient operating life of the wire ropes. For hoisting gear and cranes, this is done according to the DIN 15020 standard with mechanism groups and the direct calculation of the rope diameter.

Using the “Leipzig” method simplified for the TGL 34 022 standard, it was possible to mathematically estimate the bending cycles of wire rope constructions for visible and non-visible wire breaking development in rope drives generally. The rope diameter was defined from the safety factor in conjunction with the required operating life. This was the first time that the “sufficient time of bearing” could be calculated for rope drives according to DIN 15020. The “Leipzig” method integrates the experimental results of the former WBK rope testing body Bochum. Comparisons with the “Stuttgart” method showed both differences and extensive agreement of bending cycles tolerated with mathematical probability. Rope drive analysis by means of a “rope harp shape” is a way of calculating the bending cycles acting in rope drives and other stresses from the operating conditions of the ropes.

In the new preliminary standard DIN CEN/TS 13001-3-2, the rope diameter is defined from one of two limit design rope forces. The interactions resulting from the proof procedure continue the tradition of dimensioning according to DIN 15020. However, the method of calculating the total bending cycles could raise excessively optimistic expectations on the service life of the wire ropes in the interactions of dimensioning, and signs of fatigue not detected in time may cause risks or even rope breakage.

O. Vennemann and B. Ernst

ODN 0844

155

*A practical approach to the prediction of lifetime of large diameter multi-layer wire ropes for use in deepwater deployment systems*

Torque neutral or low torque wire rope constructions of large diameter are used to satisfy the increasing demands of installing large structures in great water depths. For these types of wire rope it becomes very important to monitor the integrity of the rope throughout its lifetime via an integrated rope monitoring system.

This process can be based on monitoring of the usage of each rope section in terms of load and accumulated bending cycles in combination with a rope inspection programme covering non-destructive inspection techniques and visual inspection. The prediction of the rope lifetime based on its usage is an integral part of such a rope monitoring system.

A benchmark has been set by a series of laboratory bending fatigue tests with frequent magneto-inductive inspections and visual examinations. This test series acts as the basis for the prediction of the rope lifetime for the tested wire rope constructions.

Throughout its service life the usage of the ropes in terms of bending cycles and loads is monitored constantly and accompanied by magnetic and visual inspections to determine the rope damage per section due to bending fatigue, wear and tear and internal corrosion.

This article covers the requirements for a successful integration of a rope monitoring system in subsea deployment systems; elaborated conclusions on the advantages of the application of such a system are made.

D.A. Sayenga

ODN 0845

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*Innovative ropes and rope applications*

Our theme of this conference in Stuttgart is Innovative Ropes and Rope Applications as we celebrate the 175<sup>th</sup> anniversary of wire ropes. Tonight I hope to observe similarities of these two concepts as a way to emphasize how we can achieve more in the future by having a better understanding of the past. The two concepts are similar but not exactly identical. Innovative *ropes* are solutions that evolve in response to pre-existing questions. Innovative *applications* are questions that arise in connection with pre-existing solutions. Neither can suddenly appear in a vacuum. Each depends upon a previous state of affairs.

R. Ashkenazi

ODN 0846

181

*The performance of synthetic ropes under extensive traction fatigue tests*

This paper will present some topics with regard to the difference in fatigue and traction behaviour of wire and synthetic ropes. Results of traction fatigue tests on samples of synthetic and wire ropes for an elevator application will be presented. The results show good traction performance under specific roping method and machine parameters. Moreover, these results demonstrate and emphasise the potential of synthetic ropes to be applied for high rise application.

O.R. Berner

ODN 0847

191

*Endurance of wire ropes in traction applications*

In traction elevators wire ropes are degraded through multiple effects. Besides special groove geometries, which increase the contact pressure between the rope and the traction sheave, creep and slip effects are inevitable in traction applications. The rope endurance is thereby significantly reduced. To date the calculation factors applied for the dimensioning of elevator ropes according to EN 81-1 [1] have been derived from unspecified field data of elevators built before 1980, regarding only rope constructions with fibre core. Due to this fact it is crucial to assess the impact of the latest technological changes in elevator and rope design and accomplish a systematic analysis of the specific rope deterioration mechanisms.

Since the rope deterioration in traction elevators can not be simulated with regular bending machines a comprehensive research project was initiated at the Institute of

Mechanical Handling and Logistics (IFT) in 2003. Financed by the Federal Ministry of Economics and Technology an extensive test program running over a period of almost five years was conducted with participation and support of different elevator and rope manufacturers. Utilising a traction test bench at the IFT, specially built for this project to reproduce rope deterioration in elevators, different rope constructions were tested in combination with varying traction sheave groove shapes. The results of the project can be used for an updated rope dimensioning in the elevator standard.

The paper will present the results and analysis from these extensive tests.

D. Raupp

ODN 0848

205

*Swaged fittings under tension and fatigue loads*

Although swaged terminals have become increasingly important for structural engineering and mechanical handling, no technical standards exist either for production or structural analysis. Due to the complex behaviour of the components (terminal and wire rope) analytical calculations are not available to estimate the load capacity of swaged terminals under tension or fatigue loads.

Only a few design recommendations are available, which are based on geometric parameters and experimental data. Therefore the load capacity of the swaged terminal was investigated in a PhD thesis at the University of Stuttgart. The task was split into a theoretical and an experimental section. Analytical formulas were derived using the Finite-Element-Method to describe the behaviour of wire rope and sleeve after swaging. For this wire rope termination in combination with open spiral strands the fatigue properties were investigated in a systematic test program.

Due to the non-uniform methods of analysis, available test results cannot be applied directly to other rope constructions and terminations. Current standards define endurance loads for defined rope types and termination such as cast sockets. For a safe dimensioning it is necessary to specify mechanical closure and fatigue conditions considering stress and amplitude depending on swaging parameters and material.

U. Briem

ODN 0849

219

*Total fatigue behaviour of running ropes*

Dynamic stresses of mechanical elements lead to material fatigue. In the past individual fatigue modes for ropes were investigated separately for different stresses. The most detailed investigations have been made for alternating bending stress. Fewer investigations about pulsating tension-tension stress and oscillating torque stress have been made. Fatigue tests on ropes which were stressed by a combination of dynamic stresses have mainly been made for fluctuating bending and tension stress. For this combination of stresses an equivalent single alternating bending stress was used. Fatigue tests with combined stresses have hardly been made. An equation to determine the number of cycles the rope will endure in such cases does not exist. In the following a theoretical model will be presented with which the total fatigue behaviour of running ropes which may be loaded by various dynamic stresses can be described. An equation to model the expected lifetime will be introduced.

J. Kowalski, J. Nowacki and A. Tytko

ODN 0850

231

*Database method for supporting the condition assessment of modern wire ropes*

It is obvious that various wire ropes used in different applications behave (work) differently. The endurance depends on so many factors: construction, different mechanisms of degradation, environmental conditions and human factors as well. According to ISO and European Standards concerning wire ropes the most popular discard criterion is loss of metallic area. It is measured by NDT means (Magnetic Rope Testing - MRT) or visually (Visual Testing - VT) by number of broken wires or loss of metallic area. New (modern) constructions of ropes have been used in specific applications for more than ten years. Compacted ropes and ropes with modern sophisticated cores are very popular. After more than ten years of observations in ropeways it is clear that such ropes behave differently compared to typical stranded ropes with fibre core.

Almost no broken wires, corrosion and elongation are observed. This means that discard criteria based on loss of metallic area are insufficient to assess the state of such wire ropes. The authors suggest that during periodic inspections more parameters should be taken into account. For example: local lay length and diameter changes, not typical "odd" MRT traces, visual inspection of the rope surface, local geometrical changes, X-ray inspection, etc. The problem is that hauling and carrying ropes in ropeways work for a very long time, sometimes more than 30 years. During such a long time it is difficult to collect many different data without knowledge, of which factor in the future will determine that the wire rope should be discarded. The solution could be a database system designed for different data formats, which are collected during the periodic wire rope inspections. The authors present such a dynamic database system. It allows not only collecting of data but their analysis and presentation as well. The system can help store data from modern visual inspections of ropes as well as different information about the rope installation, MRT equipment, environmental conditions, visual and additional tests results etc. The system will help also in managing all inspections, generating reports and scheduling the next date of the wire rope inspection.

B. Longatti

ODN 0851

241

*Findings and developments following the Schilthorn Incident*

A dramatic incident at the Schilthorn a renowned aerial tramway, almost ended in disaster. The sudden loss of more than 50% of the metallic cross-section of a locked coil track rope due to a deterioration mechanism (Hydrogen Induced Stress Corrosion Cracking (HISCC)) unknown within rope and ropeway professional circles in the context of a locked coil rope, roused the whole ropeway community!.

The damage to the rope was caused by the jerky stick-slip movement of the rope over the deflection saddle during the first track rope relocation 26 years earlier.

Visual inspections subsequently carried out on aerial tramways of similar build, brought to light the existence of surface damages in an unexpectedly high number of track ropes.

Industry experts analysed the cause, the potential and nature of this "new" wire damage, its development mechanism and investigated aiming at the improvement of rope cleaning equipment and procedures, at efficient ways of rope repair and at long term, reliable damage monitoring. The prevention of such type of wire and rope damage was another topic no less important, that led to redesigned track rope deflection subsystems and improved track rope relocation procedures, almost immediately. Newly built aerial

tramways and those already existing undergoing a major overhaul are the beneficiaries of all those findings.

The propagation of existing wire and rope damage can be retarded or even stopped with the adequate measures: reliable visual inspections and efficient repair methods.

F. Sloan

ODN 0852

259

*Damage mechanisms in synthetic fibre ropes*

Synthetic fibre ropes are widely used in applications involving frequent deployment and movement by personnel, for example ship mooring lines, tug lines, etc. However, where large ropes run continuously at high tensions over sheaves, such as elevators and cranes, the use of synthetic fibre rope has not found wide use because of relatively poor fatigue life. Damage mechanisms in synthetic fibre ropes are reviewed and compared with steel wire rope where possible. As with steel wire ropes, excess heat generated during cyclic bending over sheaves can decrease the life of synthetic fibre ropes. However, the onset of degradation in polymer fibres can begin at much lower temperatures, as low as 60°C. Therefore particular attention is paid to mechanisms that contribute to heating, for example hysteresis caused by fluctuating loading, and sliding friction caused by fibres movement during bending. Methods to reduce frictional heating are discussed. Models are presented for scaling small-rope experimental data to predict large-rope fatigue life.

J. van Rensburg, R. Rontgen, G. Rebel and B. Schmitz

ODN 0853

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*Update concerning the premature discard of 45 mm ropes operating on a Blair multi-rope rock winder*

Driefontein Gold Mine installed four 2500 m long 45 mm diameter round strand ropes on the No. 2 Shaft Blair Multi-Rope (BMR) Rock winder, located southwest of Johannesburg. The rope with eight compacted outer strands and a plastic coated steel core was selected for hoisting of ore in a 2043 m deep vertical shaft.

In May 2006, two of the ropes on the one BMR drum had to be discarded due to excessive broken wires in the outer strands detected during routine magnetic testing. These ropes, as a pair, had completed only 35,000 cycles. The two ropes on the other BMR drum showed no damage at this time. On 20 June 2006 the remaining two ropes were discarded at 38,000 cycles also due to excessive broken wires in the outer strands.

This follow-up paper describes:

- the history of ropes used on the winder prior to the installation of the round strand ropes;
- the aspects relating to the use of round strand ropes;
- the findings of the investigators; and,
- a detailed discussion of the failure mechanism.

A. Canova, F. Degasperi, F. Ficili, M. Forzan and B. Vusini

ODN 0854

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*Experimental and numerical characterisation of ferromagnetic ropes and non-destructive testing devices*

The paper mainly deals with the magnetic characterisation of ferromagnetic ropes. The knowledge of the magnetic characteristic is useful in the design of non-destructive testing equipments with particular reference to the design of the magnetic circuit in order to reach the required rope magnetic behaviour point. The paper is divided into two main sections. In the first part a description of the experimental procedure and of the provided setup devoted to the measurement of the non linear magnetic characteristic of different rope manufactures and different types is presented. In the second part of the paper the magnetic model of the ropes is developed for the simulation of a non-destructive device under working conditions. The simulation is provided with a non linear three dimensional numerical code based on the Finite Integration Technique. Finally the numerical results are compared with some experimental tests under working conditions.

H. Usabiaga and D. Durville

ODN 0855

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*A finite element approach for modelling wire ropes*

As mentioned by Ziegler and Wehking, modelling wire rope by means of the finite element method has many advantages in comparison with the analytical models. Although the finite element method is more widespread in many industrial applications, it has not been markedly used for modelling wire ropes. The modelling of wire ropes with this method requires many degrees of freedom and involves various non-linearities. Consequently, in most of the cases, a simple wire rope cannot be modelled precisely within a reasonable CPU time. Until now, solid finite elements have been mainly used for modelling wires. In this paper the proposed approach uses beam finite elements for modelling wires, and beam-to-beam contact elements for modelling inter-wire contacts. This approach requires a lower number of degrees of freedom for modelling the rope, and consequently enables more complex modelling and/or longer ropes to be used within a reasonable period of time.