

# THE MECHANICAL BEHAVIOUR OF CONDUCTORS AND FITTINGS

Working Group B2.11



Temple of Aeolus, the ancient Greek God of winds, Athens, 4th century B.C.  
(picture courtesy Sakis Karagiorgas); insert: broken conductor due to  
fatigue caused by aeolian vibrations (picture courtesy Louis Cloutier)

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## **A WORD FROM THE CONVENOR**

Since the very beginning of electric power transmission, transmission lines have been and still are the backbone of the electricity grids; they are thus indispensable not only in industrialised countries with their ever growing demand for electricity, but also in developing countries, where electricity stands for a "brighter" future.

From all the components of a transmission line, conductors are the only ones with an "active" duty, since they have to carry and transport the electric power. So it comes as no surprise that their study has attracted the interest of the industry from the very beginning in order to guarantee safe performance of the network. However, whilst electrical conductors look simple to the layman, they are in reality quite complicated structural elements and pose demanding mechanical and electrical problems to the engineers who have to study their behaviour.

Conductors are subjected to rather complicated combinations of high mechanical, electrical and environmental stresses. Of particular importance for the reliability of lines are conductor problems related to wind induced vibrations such as aeolian vibration, galloping and subspan oscillation. Quite often, these phenomena are the reason for conductor failures with partly catastrophic effects. Design aspects of conductor fittings also play a major role in this respect, for instance in the design and choice of adequate damping devices. The design of fittings for newer conductor applications is particularly important, such as in the combined use of conductors and earth wires for the transmission of information in its various forms. All in all, a very demanding field that for the reasons mentioned above, has attracted the attention of suppliers and users, practical design engineers and academia.

From its founding days, CIGRE has been a melting point for activity related to this subject and in the course of the years, has performed groundbreaking work in this field and acted as a distributor of knowledge worldwide. This is evident by the number and quality of CIGRE papers published in *Electra* over the last 70+ years. It is my pleasure and privilege as convenor of Working Group 11 on "Mechanical Behaviour of Conductors and Fittings" to present this thematic brochure to the interested parties.

This brochure covers all *Electra* papers prepared by Working Group 11 and also its predecessors, Working Groups 01 and 04. It also includes the chronology of WG11 by ex-convenor Dave Havard. A "management summary" by convenor-elect David Hearnshaw and a "historical" review of WG04 by ex-convenor Walter Bückner and WG01 by ex-convenor Magnar Ervik complete this important work. All of them deserve our thanks for the work they have done. Special thanks are also due to the ever-active Peter Dulhunty - the son of the working group living legend Philip Dulhunty - for preparation of the CD and to Umberto Cosmai for his valuable contribution in the preparation of the Synthesis. Last but not least I would like to use this opportunity to thank all authors and all past and present working group members. They are the people who have shaped the WG11 success story, making it the largest and possibly one of the most productive working groups in CIGRE.

May this thematic brochure help transmission line engineers dealing with these issues to find the proper answers and may it also become for them the proper background for future advances in this fascinating field.

**Dr. Konstantin O. Papailiou,  
Convenor WG B2.11  
Winterbach by Stuttgart, June 2004**



**CIGRE SCB2 – WG 11**  
**'THE MECHANICAL BEHAVIOUR OF CONDUCTORS AND FITTINGS'**  
**THEMATIC BROCHURE**

**INTRODUCTION**

This brochure brings together in one document all the Electra papers published since 1970, which are the fruits of the work of WG11 and its predecessors, WG01, WG02 and WG04. By its very nature, work on vibration has continued over many decades and these papers do not represent 'final' results, therefore it is intended to update this brochure from time to time.

A brief history of WGs 01, 02 and 04 based on a submission by Dr Walter Bückner (Convenor WG04) and Magnar Ervik (Convenor WG01) is given in Appendix 1 to this brochure.

**History**

Transmission line conductors and their fittings have been on the agenda of CIGRE meetings since as far back as 1926 with reports of conductor damage emerging in the 1930's. In 1953, CSC6 established the EDS panel to collect data worldwide on in-service experience with conductors and this resulted in EDS recommendations being published in CIGRE paper CSC6-61-3 in 1961. However, concerns emerged in CIGRE paper CSC6-62-5 in 1962 as to the limitations of the EDS recommendations and as a direct consequence, WG01, WG02 and WG04 were established to study 'Vibration Theory', 'Dampers and Fittings' and 'Endurance Capability of Conductors' respectively. WG02 was merged with WG01 in 1971

In 1987, WGs 01 and 04 were merged together to form CIGRE SC WG11 with specific work targets, under the leadership of its first Convenor, Mr. Rolf Ruritz. The work was to include both static and dynamic behaviour, and also was seen as a logical successor to the two earlier working groups, WG01 and WG04, which were targeted at theoretical and measurement approaches to the range of problems.

WG11 is intended to be of a permanent nature and is seen as the best way of handling the broad topic of 'The Mechanical Behaviour of Conductors and Fittings', which has many 'sub topics'. Expertise is retained and the opportunity for international experts to exchange experience is provided.

**Scope and Development of WG11**

The theoretical work was to be extended to different classes of damping systems and terrain conditions, and to employ data from field and laboratory studies. In pursuit of this aim, the expansion of the data bank on the fatigue of conductors in the field under different wind exposures was considered to be of critical importance. The "safe border line", which serves as a guide to avoid conductor fatigue damage at clamps, would be developed and refined for application to different classes of conductor, as well as for different wind conditions.

The work was expected to lead to the selection of optimal design tensions to safely avoid fatigue due to aeolian vibration for different conductors and wind conditions. New design rules to encompass

different damping systems were also envisaged. Studies of the effect of different tensions on the cost of new overhead lines were seen to be an area of work with significant economic benefit. This was somewhat overtaken by the world wide reduction in new construction and the focus was shifted to application of these studies to upgraded and uprated older lines.

Galloping of conductors received particular emphasis by incorporation of a CORECH work group within CIGRE WG11. The focus was on recent field observations of galloping, effectiveness of control devices, documentation of damage, refinement of clearances required for design to avoid flashovers and instrumentation to record galloping. Emphasis was also placed on research on aerodynamics, on shapes of accretions of ice or wet snow and on the development of theories describing galloping behaviour.

The WG recognized the importance of maintaining awareness of new and developing technologies. These included UHV and compact lines, new designs of fittings - especially spacers, clamps, spacer-dampers, interphase spacers and optical fibre cable fittings. The production of user-friendly guides for the industry was seen as one of the WG's primary aims. Subsequently, the needs of the industry led to the establishment of a wide range of task forces focused on the problems of bundle conductors including wake induced oscillations, and acceptance testing methods for fittings, such as dampers, spacer-dampers and optical fibre cable fittings.

### **Achievements of WG11**

The legacy of WG11 lies in its publications and those of its progenitors, WG01 and WG04. These publications trace progress in three of the areas for which WG11 is responsible and against which its performance against its objectives may be measured.

#### **Aeolian Vibration**

Overviews of the technology of aeolian vibration of overhead lines are found in working group reports in *Electra* Nos. 120, and 124. The former describes the field measurement approach to the problem. Associated publications are: "Recommendations for the Evaluation of Lifetime of Transmission Line Conductors," *Electra* No. 63; "Guide for Endurance Tests of Conductors Inside Clamps," *Electra* No. 100; and "Guide to Vibration Measurements on Overhead Lines," *Electra* No. 163.

The report in *Electra* No. 124 was an update and expansion of Paper 22-11 of the 1974 Session. Those reports pursue the analytical approach to the aeolian vibration problem. Associated publications are: "Guide on Conductor Self-Damping Measurements," *Electra* No. 62; "Guide on the Measurement of the Performance of Aeolian Vibration Dampers for Single Conductors," *Electra* No.76; "Modeling of Aeolian Vibration of Single Conductors – Assessment of the Technology," *Electra* No. 181; "Safe Design Tension with respect to Aeolian Vibration – Single Unprotected Conductors," *Electra* No. 186; and "Safe Design Tensions... - Damped Single Conductors," *Electra* No. 198.

#### **Conductor Galloping**

A state-of-the art report *ca.* 1970 was published in *Electra* No 12. Two papers published on the "kissing phenomenon" in the 1980s - *Electra* No 81, 1982 and *Electra* No 90, 1983 – detailed a secondary effect of an antigalloping design based on spacer removal, as used on twin conductor in some countries. The conductor 'kiss' generates a high level of audible noise and increases conductor

reactance. Electra No. 94 presented, "Damage to Overhead Lines caused by Conductor Galloping," which summarized the results of a survey of utilities in member countries. "Field Observations of Overhead Line Galloping – Galloping Reporting Forms," was published in Electra No.162 to encourage uniformity in compiling data on galloping episodes. As a reference for the line designer, Electra No. 191a published, "Review of Galloping Control Methods."

### **Fittings**

In 1989, the WG published, "Guide on the use of Bolted Suspension Clamps," Electra No. 123. During 1996 – 2001, the WG published a report on 'Results of the Questionnaire on Interphase Spacers', ELECTRA No 143 and a series of reports on fittings for fibre optic cables in overhead lines: "Results of the Questionnaire – 'Fittings for Fibre Optic Cables in Overhead Lines'," Electra No. 165; and guides covering selection and use (Electra No. 176), testing procedures for optical ground wire and optical conductor fittings (Electra No. 188), and testing procedures for fittings for all-dielectric self-supporting and optical attached cables (Electra No. 191b). There is no doubt that the WG has led the way in the categorizing fittings for the various types of optical fibre cables and defining their test methods.

### **Future Publications**

A number of papers will be offered for publication, or be published, in the near future and will be included in the second issue of the brochure. These include: -

- ▶ 'Modelling of aeolian vibrations of single conductor plus damper'
- ▶ 'A survey of fittings for high temperature conductors'
- ▶ 'A survey of Aircraft Warning Devices'
- ▶ 'A three-part state of the art paper on Spacers and Spacer Dampers'
- ▶ 'State of the art of conductor galloping brochure'
- ▶ 'Experience with the fatigue endurance of conductor/clamp systems and the development of engineering guidelines'

This body of publications will continue to grow, as the technology of overhead lines evolves.

**D Hearnshaw**  
**August 2003**



**ELECTRA Papers 1967 – 2003 (Electra No.1 – 209)  
relating to 'Mechanical Behaviour of Conductors and Fittings'**

Electra No.	Author(s)	Title
12	A.T. Edwards	Conductor galloping
24	WG 05	A practical method of conductor creep determination
62	SC 22/IEEE	Guide on conductor self-damping measurements
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75	WG 05	Permanent elongation of conductors
76	SC 22/IEEE	Guide on the measurement of the performance of aeolian vibration dampers for single conductors
81	P.H.Lepers, J.L.Lilien	The Behaviour of spacerless bundles. Attraction and release values arising from high load currents
90	H. Adami, P.H.Lepers, J.L.Lilien	The behaviour of spacerless bundles due to high load currents. Experimental results and theoretical calculations.
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143	WG11/TF03	Results of the questionnaire on interphase spacers.
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163	WG 11/TF 02	Guide to vibration measurements on overhead lines
165	WG 11/TF 03	Results of the questionnaire: Fittings for fibre optic cables on overhead lines
176	WG 11/TF 03	Guide to fittings for optical cables on transmission lines (Part 1, Selection and use)
181	WG 11/TF 01	Modelling of aeolian vibration of single conductor: Assessment of the technology

186	WG 11/TF 04	Safe design tension with respect to aeolian vibrations (Part 1: Single unprotected conductors)
188	WG 11/TF 03	Guide to fittings for optical cables on transmission lines (Part 2A, Testing procedures, Optical ground wire fittings and optical phase conductor fittings)
191a	WG11/TF06	Revised galloping control methods
191b	WG11/TF03	Guide to fittings for optical cables on transmission lines (Part 2B, Testing procedures all dielectric self supporting cable fittings and optical cable attached cable fittings)
198	WG11/TF04	Safe design tensions with respect to aeolian vibrations. – Part II – Damped single conductors with dampers).
209	WG11/TF05	Part 1 State of the Art on Survey on Spacers and Spacer Dampers: Part 1 – General Description

## **Synthesis of ELECTRA Papers 1967 – 2003 (Electra No. 12 – 209) relating to Mechanical Behaviour of Conductors and Fittings**

**A.T. Edwards**

### **CONDUCTOR GALLOPING**

**Electra No. 12 (1970)**

Presently available information on the galloping of overhead transmission lines is reviewed. This is a low frequency high amplitude type of mechanical oscillation, which usually occurs when ice adheres to the conductors. It appears that the incidence and amplitudes are significantly greater with large diameter and bundled conductors compared with small diameter conductors. The general phenomenon can be explained from aerodynamic considerations, and from these, estimates can be made on the critical wind velocity required to initiate motion and of the energy input from the wind. From knowledge of the aerodynamic characteristics, measured under static conditions, it is possible to predict with reasonable confidence, whether or not a particular shape will be unstable and the critical wind velocities to produce galloping.

The presently universally accepted method for minimising outages from the phenomenon, is to space the conductors sufficiently far apart from each other to prevent flashovers. Galloping can be controlled also by preventing ice formation, or by significantly increasing the energy dissipation capability of the transmission system at low frequency, or by the use of inter-phase spacers. Only the latter approach has been fully demonstrated at this time to have the potential of providing a suitable galloping control. This method requires some further development but appears to be technically feasible, effective and economically attractive. It may be practical to increase the energy dissipation capability of the transmission system at low frequency, such as by the aerodynamic dampers, in-span dampers or by other means, but more development and experience is required with this approach to fulfil all the engineering requirements. The prevention of ice is practical for specific lines but not as a general solution to the galloping problem. Two ice prevention methods are described.

**Study Committee 22, Working Group 05**

### **A PRACTICAL METHOD OF CONDUCTOR CREEP DETERMINATION**

**Electra No. 24 (1972)**

Transmission line conductors must maintain clearance above ground obstructions as required by regulations. Minimum clearance occurs at final sag conditions. The nonelastic elongation of a conductor that determines final sag, starts during conductor installation and continues for the life of the line. This nonelastic elongation may be from initial ice and wind loads or from long time loading at any tension and temperature levels, commonly called creep, or from a combination of the two. Strand settlement is a considerable part of both types of nonelastic elongation during the first few days after installation. This report presents a practical five-step method for determining this total nonelastic elongation and the resulting final sag. It is applicable to meet any condition throughout the world and an individual user can considerably simplify the mechanics for applying it to his own installation methods and operating conditions. A graphic method of converting the creep allowance for use in the field is also described. Tools for estimating, within reasonable limits, the creep of any ACSR and AAAC conductors are provided. The procedure presented in this report is based on the experience of the Boneville Administration and on a series of tests and investigations on conductor behaviour from a number of Countries, together with discussions within the Working Group, whose Convenor, Mr P.F. Winkelman, was largely responsible for this method of approach.

The method is intended for the use of transmission line engineers who are concerned more with getting the answers than understanding the technical and mathematical background.

**CIGRE Study Committee 22 and IEEE Transmission and Distribution Committee**

### **GUIDE ON CONDUCTOR SELF-DAMPING MEASUREMENTS**

**Electra No. 62 (1979)**

This Guide has been prepared jointly by the IEEE Task Force on Conductor Vibration and the CIGRE Study committee 22, Overhead Lines, Working Group 01 on Mechanical Oscillations. It has been also published by IEEE, with the same title as: Standard 563-1978. This Guide is the first in a series of guides planned to establish universally accepted procedure and parameters for developing methods for controlling aeolian vibration. It has been prepared for the purpose of standardizing the measurements of the inherent damping characteristics of conductors. The methods available for these measurements can be divided into two main groups, which are usually referred as the "free vibration" and "forced vibration" methods. The proposed free vibration method consists in the recording of the decay of conductor vibration in a principal mode after the exciting force has been disconnected and the other modes have decayed to insignificant values. The energy dissipation can then be derived from the rate of the vibration decay. This method can be greatly affected by

the system used to disconnect the driving force, as the slightest disturbance of the conductor causes the generation of other vibration modes. Two forced vibration methods, in which the conductor is forced into resonant vibration by an electro-dynamic shaker, are suggested. The first is the "power method" in which the power dissipated by the conductor, is determined directly from the product of the excitation force and the resulting velocity at the point of application of the load. The second is the "standing wave method" in which the power transfer from the shaker toward the ends of the span, at any particular node is derived from the ratio of the nodal to anti-nodal amplitude.

The guideline provides also detailed information on the requirements for the test span arrangement, the conductor conditioning and the test procedures, and suggests the form in which the results should be presented.

#### **Study Committee 22, Working Group 04**

### **RECOMMENDATION FOR THE EVALUATION OF THE LIFETIME OF TRANSMISSION LINE CONDUCTORS**

#### **Electra No. 63 (1979)**

The WG 04 members and some related companies have been heavily engaged in investigating the endurance capability of overhead transmission line conductors, during the past 8 years. The tests were performed applying usual methods of testing materials and structures. To do that, first the stress-cycle to fracture relationships – one step S-N curves – of several types of aluminium-based conductors under service conditions were evaluated in laboratory tests. The fatigue strength of stranded conductors has been found discernibly lower than that of separate wire due to fretting influence. For a group of stranded conductors, the results of the tests are somewhat different due to unavoidable influences of conductor type, wire material, test procedure damage criteria and mean stress. The method of determining the lifetime of transmission line conductors described in this report is in accordance with the present state of knowledge of material behaviour and with the practical experience of lifetime of transmission line conductors. Endurance capability has been determined with a conservative safe-borderline applicable for normal quality conductors and normal type of clamps. Numerous examples are given and explained for the accumulation frequency curves. These curves vary to a large extent. The parameters accounting for this are terrain factor, type of conductor, type of suspension, etc.

Questionnaire results obtained from more than 50 authorities show a qualitative conformity about the significance of the various parameters between the WG 04 results and the results from practical experience. The lifetime of conductors is influenced by the quality of the manufacturing especially that of aluminium strands. Poor erection technique can also reduce the conductor lifetime to a considerable extent.

#### **Study Committee 22, Working Group 05**

### **PERMANENT ELONGATION OF CONDUCTORS. PREDICTOR EQUATION AND EVALUATION METHODS**

#### **Electra No. 75 (1981)**

This paper deals with the experimental research, performed in recent years, to achieve more general empirical laws on conductor creep in which all the external and internal factors influencing the phenomenon should appear in order to predetermine creep during the life of the line by analytical means. Two distinct methods of research have been adopted. The first consists in laboratory tests on complete conductors of different type and permitted to formulate analytical relationships that make it possible to calculate creep, depending on the type and nature of the conductors examined. The second method provides laboratory tests on single wires. In this case too, by means of few calculation steps, analytical relationships are formulated that make it possible to calculate creep in the complete conductor.

The studies carried out complete and rationalize the methods presented in the paper "A practical method of conductor Creep determination" published in Electra No. 24.

This report contains:

- the qualitative description of the development of permanent deformation of a conductor subjected to constant mechanical tension, or else variable tension over a period of time;
- the analysis of the two main methods of ascertaining the permanent elongation, the relevant test procedures, the measurements and the interpretation of the results; the advantages and drawback of both methods are also discussed;
- the predictor equations evaluated by tests on the complete conductor and by tests on component wires;
- the calculation methods for the evaluation of conductor permanent elongation during the life of the line.

**CIGRE Study Committee 22 and IEEE Transmission and Distribution Committee  
GUIDE ON THE MEASUREMENT OF THE PERFORMANCE OF AEOLIAN VIBRATION DAMPERS FOR  
SINGLE CONDUCTORS**

**Electra No. 76 (1981)**

This Guide has been prepared jointly by the IEEE Task Force on Conductor Vibration and the CIGRE Study committee 22, Overhead Lines, Working Group 01 on Mechanical Oscillations. It has been also published by IEEE, with the same title as: Standard 664-1980. This Guide is the second in a series of guides planned to establish universally accepted procedures and parameters for developing methods for controlling aeolian vibration. The basic engineering approach to the control of overhead conductor vibrations is to compare, at an acceptable amplitude, the wind power input with the power dissipated by the conductor and supporting structure and hardware. The difference between these two quantities is the amount of power that ideally should be dissipated by a vibration damping system when attached to a single conductor at one or more appropriate locations. The CIGRE/IEEE Guide on Conductor Self-damping Measurements (see Electra No. 62) sets out the procedures for determining the power dissipated within the conductor and is a basic reference for this guide. This document describes the procedures for determining the performance of vibration damping systems. Since the engineering objective is to quantify the power dissipated by a damper installed on a conductor as a system, it is recommended that the measurement be performed on a laboratory span utilizing the conductor for which the damping system is intended. Two forced vibration methods are available for measuring the power dissipated by the conductor and the relevant damping system. The first is the "power method" in which the power dissipated by the system is determined directly from the product of the excitation force and the resulting velocity at the point of application of the load. The second is the "standing wave method" in which the power transfer from the shaker toward the ends of the span, at any particular node is derived from the ratio of the nodal to anti-nodal amplitude.

**P.H. Leppers – J.L. Lillien**

**THE BEHAVIOUR OF SPACERLESS BUNDLES – ATTRACTION AND RELEASE VALUES ARISING  
FROM HIGH LOAD CURRENTS**

**Electra No. 81 (1982)**

On high voltage transmission lines with conductors of  $\phi \leq 25$  mm, experience has shown that uncoupling of bundles in the vertical or diagonal arrangements gives an adequate remedy against large amplitude oscillations and phase-to-phase faults caused by galloping. However, an unspaced twin bundle may produce side effects at load current conditions, such as reduction in sub-conductor spacing or collapse, with subsequent increase in the strength of the electric field, increase in impedance and considerable audible noise at contact (100 Hz). The CORECH Working Group on galloping, initiated by the Comité de la Recherche of Unipede, decided to perform a study into the phenomenon of collapsing which may occur in unspaced bundles. At the request of Laborelec, the University of Liege has carried out analytical studies.

The behaviour of a spacerless bundle, under high load currents giving rise to collapsing of the conductors, is a complex problem due to the numerous parameters which influence the phenomenon (in addition to the electromagnetic and electrostatic forces, other factors should be taken into account, such as the effect of gravity, the conductor elasticity, the span length, heating, anchoring, conductor clamps, etc.). With a simple mechanical model (pendulum) the problem can be easily made static (assuming a parabolic shape of the catenary in a plane whose axis is a straight line between the anchoring points). In this way, a basic formula to determine the attraction values acting between sub-conductors at load current conditions has been drawn up. The proposed formula could also be transposed to express, for a given attraction current, the critical span or mechanical tension. It is also possible to calculate the come-together current for bundle with spacers replacing, in the formula, the span length with the sub-span length.

**H Adami - P.H. Leppers - J.L. Lillien**

**THE BEHAVIOUR OF SPACERLESS BUNDLES DUE TO HIGH LOAD CURRENTS. EXPERIMENTAL  
RESULTS AND THEORETICAL CALCULATIONS**

**Electra No. 90 (1983)**

This paper describes load current test results on unspaced vertical and diagonal bundle configurations, and gives information about the relation between collapsing currents and spacing. In Electra No. 81 (1982), the theoretical approach of the phenomenon attraction and releasing of spacerless bundles at high load currents is presented. This paper deals with the continuation of that study, which purpose was to provide a simple formula, based on experimental and analytical considerations, to determine the collapsing and the releasing current at different line parameters. Tests were carried out on full-scale and reduced scale models, in order to define the relation between electromagnetic attraction caused by load currents and line span characteristics, and to compare the test results with calculated values. The test results confirm that

unspaced vertically or diagonally configured bundle conductors have good inherent stability. Moreover, they eliminate spacer problems, reduce the line costs and give less galloping problems if low conductor torsional stiffness is supposed. However, electromagnetic attraction of spacerless bundles under high load current conditions, will reduce the midspan conductor spacing. If a critical value is reached, the bundle may collapse. This side effect will cause operating problems. Calculation and line test indicate, for example, that in a vertical spacerless bundle of medium size conductor, under actual line conditions, the conductors usually will not come together at the highest conductor current capacity permitted, if the vertical conductor midspan spacing is about 1.5 times the yoke spacing. In the case of a collapsed twin bundle, the current must be reduced to about 60% of the initial collapsing value before the conductors release and return to the original position.

**R.R. Gibbon – P.H. Juul – H.B. White – W.J. Wijker of Study committee 22  
DAMAGE TO OVERHEAD LINES CAUSED BY CONDUCTOR GALLOPING  
Electra No. 94 (1984)**

This report presents the results of a questionnaire sent to all utilities which were known to have experienced line damage due to galloping or who had climatic conditions conducive to galloping. The survey of the damage to overhead lines by conductor galloping has confirmed that the majority of electrical utilities have experienced moderate to severe galloping activity and damages. The cost of such damages and the possibility that it may increase with line age, is of concern to many electrical utilities. However, it has not been possible to confirm or deny that damage to overhead lines caused by galloping has increased in recent years. Recording of galloping movements and conditions that cause them, is generally inadequate for establishing the importance of basic design parameters. The survey did not support the assumption of elliptical conductor orbits or that single conductors are more likely to gallop than bundled conductors. Galloping does appear to be more prevalent in flat terrain. The wide design differences between line constructions that have experienced severe conductor galloping indicate that general solutions to the problem may not exist. Some particular solutions appear to be promising, while some particular constructions appear more likely to experience damage. There are therefore several design choices, with regard to the disposition of the phases or application of devices, which are used to reduce the incidence of faults due to conductor clashing. Most of the information received was from recent years. This means that trends connected with ageing or changes in design could not be found. It is therefore necessary to repeat the survey within ten years, when more valuable insights as to the ageing deterioration of lines due to galloping will be obtained.

**Study Committee 22, Working Group 04  
GUIDE FOR ENDURANCE TESTS OF CONDUCTORS INSIDE CLAMPS  
Electra No. 100 (1985)**

Fatigue failures of overhead line conductors due to aeolian vibration occur at the mouth of suspension clamps and other fitting clamps, where maximum bending stresses are combined with fretting. It has been proven by laboratory tests that the endurance of overhead conductors is much smaller than that of single wires due to fretting and that the clamp hardware has a remarkable influence on the conductor endurance. To investigate the influence of clamps, bending fatigue tests are advantageous. This guide has two different aims. First, to get a safer base for an endurance assessment of actual lines by application of the method published in Electra No. 63. The second is to improve the design of clamps in order to prevent early failures due to aeolian vibrations. To arrive at comparable results in different laboratories, an agreement on important test parameters and on a uniform test method is necessary. Preferred type of testing is the alternate bending of the conductor, at constant amplitude, in close approximation with the vibration mode in actual lines. The resonance type of vibration, with power input by shaker or any other equivalent method, is proposed. Mean static stress and angle between clamp and the conductor should be representative for actual prevailing line conditions. The free length of the test span should be at least 5 m, in order to minimize inhomogeneous load distribution to the wires. The means for the characterization of the bending stresses should be applicable to field measurements too. It is suggested to perform both a direct measurement of the strain amplitude of the outer wires close to the clamp and of the bending amplitude defined in the IEEE Recommendations. Three broken wires or 10% of the aluminium wires, whatever is smaller, should be used as a damage criterion in respect of the relationship between the stress amplitude and the number of cycles. The tests should be run at several bending levels with at least three samples per level.

Study Committee 22, Working Group 05

## **ANALYSIS OF THE RESPONSES TO THE QUESTIONNAIRE ON STRINGING PROBLEMS**

**Electra No. 109 (1986)**

At the meeting of Study Committee 22 held in Paris during 1978, the terms of reference of WG 05 on conductors was extended to include technical problems which arose during stringing. In order that the basic facts could be determined and any general problems isolated, a questionnaire was prepared by WG05. This questionnaire consists of three parts. Part A asks general questions on the type of conductors used and procedure adopted. Part B asks more specific questions on the stringing procedures. In this section, the measurement of temperature during stringing operation was isolated as a possible area of study and specific questions on this point were raised. In addition, more general questions were raised concerning the stringing operation in order to isolate any additional areas of study that could usefully be undertaken by the Working Group. Part C consisted in two sections. In the first, detailed questions were asked on the actual parameters used to string common conductors. In the second, respondents were asked for their comments on running outblocks, birdcaging, stringing equipment, regulation and repairs to damaged conductors. With regard to the first section of Part C, two possible areas of study by the Working Group had been isolated and specific questions in these areas were asked. These areas were: a) the various ratios such as diameter of running out blocks to diameter of conductor used during the stringing operation; b) birdcaging.

The final draft of this questionnaire was circulated by the members of SC 22 in their respective Countries. By the closing date for replies, 57 replies were received from 23 different Countries. The data received have been computerized and this report summarizes the information obtained from the replies.

**Walter Bückner (Convenor of SC22, Overhead lines)**

## **RETROSPECTIVE VIEW AT THE EFFORTS MADE TO SOLVE THE PROBLEM OF AEOLIAN VIBRATION ON OVERHEAD LINES**

**Electra No. 120 (1988)**

Ever since its foundation in 1925, the CIGRE has been striving vigorously for a solution of the, already at that time, acute problem of dangerous conductor vibrations, as it is evident from numerous CIGRE reports. The CIGRE organisation has been the centre of international exchange of thoughts in this field, deciding the direction of research and publishing recommendations for the transmission line engineer. With the recommendations regarding the determination of the endurance capability of overhead line conductors published in Electra No. 63 and No. 100, the SC22 completed one more section in the field described in this paper as part of the sixty-year-old efforts of CIGRE. Based on the growing experience of many decades and on the more recent technological know-how and measuring instruments, the CIGRE method for the evaluation of the lifetime of transmission line conductors permits a reliable quantitative determination of the operating safety of existing overhead lines. For the determination of the realistic vibration behaviour of new fittings and conductors, as well as of lines already in operation or under design, it is very useful to perform measurements on lines in operation or on test lines, possibly at a scale of 1:1, if these are exposed to natural wind-induced conductor vibrations. The experience with the influence that the numerous parameters have on vibration safety will grow with the test results and will, in the course of time, also lead to more reliable designs for new overhead transmission lines, thus improving the operation reliability and economy.

**Study Committee 22, Working Group 01**

## **GUIDE ON THE USE OF BOLTED SUSPENSION CLAMPS**

**Electra No. 123 (1989)**

This guide deals with bolted suspension clamps for bare conductors and earth wires of overhead lines for transmission and distribution systems. Its purpose is to clarify and to introduce some logic into the choice of suspension clamps, by explaining why and when a certain feature of a suspension clamp may be necessary to meet the mechanical and electrical requirements. The paper indicates the main requirements to be taken into account for the design of the suspension clamps, such as:

- mechanical performance in terms of failure load and working loads
- mobility to accommodate asymmetrical loads and different spans on each side of the clamp
- sliding forces for locked clamps and slip clamps
- body and keeper profile
- turning angles to be considered in designing the clamp profile
- surface finishing to prevent damages to the conductor surface
- short-circuit capacity, considering the intensity and duration of the short-circuit currents
- electrical losses
- radio interference and Corona performance
- arrangements for live line maintenance
- corrosion resistance
- straps for counterweights

In appendix, the sliding characteristics of slip clamps and the relevant tests are reported.

## **Study Committee 22, Working Group 01**

### **REPORT ON AEOLIAN VIBRATION**

**Electra No. 124 (1989)**

This report follows the progress report of WG 01 of 1970 that can be looked upon as a snap shot on aeolian vibration technology of those times. The present snap shot is much like the 1970's but the focus is improved. The purpose of this report is to review the current status of understanding of the factor contributing to aeolian vibration of single conductor overhead lines and control of this vibration. This report is intended to discuss the contribution of the wind, the self-damping of the conductor, the damping properties of the vibration dampers and how these combine to produce the actual motions of the conductor. These motions may then be related to the fatigue of the conductor with the future goal of establishing a realistic guide for the selection of dampers for aeolian vibration control. Where the current knowledge is limited and further work is indicated, this report will act to encourage further studies. The techniques used for measurement of the properties involved, and the examination of the mechanical models used, that are available at this time, will be similarly evaluated to help identify areas for improvement. The range of uncertainty in the available data will, where appropriate, also be identified. The change from 1970 to today, involves mainly the quality of the databases that are used in the Energy balance Principle (EBP) calculations, and come about due to increased efforts to apply the EBP. Those efforts have led to a clearer understanding of the precision to be attributed to data on wind energy input, and on self-damping. Comparison of information from several organizations has shown that there is wide dispersion between the data from source to source. The WG has explored this dispersion, through sample calculations to discover its effect upon the precision of the estimates of vibration level obtained by the EBP calculations. This does not give a measure of its accuracy that is how well the EBP predicts the vibration that actually occurs on a line. Determining that accuracy requires disciplined comparisons with measured field data.

## **Study Committee 22, Working Group 11**

### **RESULTS OF THE QUESTIONNAIRE ON INTERPHASE SPACERS**

**Electra No. 143 (1992)**

The purpose of this questionnaire is to gather information about the experience of utilities around the world concerning Interphase Spacers in order to:

- list the existing and possible applications of these devices;
- estimate the stresses of these devices in service and their effects on the conductors;
- determine the efficiency and usefulness of Interphase Spacers.

The questionnaire was divided into three parts. Part A asked the utilities for the technical reasons for installation of Interphase Spacers and when they were installed. Part B was about the configuration of the line and the arrangement of the conductors. The utilities were also requested for the description and characteristics of the Interphase Spacers, and under which environmental conditions they were installed. Part C requested observations and results that had been obtained.

This report is based on answers to the questionnaire from 32 utilities that have experience in the use of Interphase Spacers. The response to the questionnaire was generally good, and the replies received came from a large geographical area. Many of the replies were from utilities that had no experience, or from utilities that had only considered the use of Interphase Spacers. According to the replies, the majority of Interphase Spacers are installed in Japan and Central Europe. They have been installed mainly to prevent galloping, but in 5% of the cases were used to compact the line. Only 19% of the Interphase Spacers have been installed for more than 11 years while 44% have been installed for 6-10 years and 37% for five years or less. Use of fiberglass in Interphase Spacers seems to be preferred for its lower weight in respect to porcelain. Application of Interphase Spacers has been successful in preventing conductor clashing or reducing the galloping amplitude.

## **Study Committee 22, Working Group 11**

### **FIELD OBSERVATIONS OF OVERHEAD LINE GALLOPING: GALLOPING REPORT FORMS**

**Electra No. 162 (1995)**

The purpose of this report is to identify the characteristics and problems of galloping, recommend ways in which trials of control devices should be conducted and provide a format for recording the information. In this way, it is hoped that an increase in the international availability of valuable data on galloping and control device performance may be promoted. Before proceeding, the relevance of the various items of information to be recorded is discussed.

The Reporting Forms, proposed in this report, provide a structured way for recording galloping observations and the associated line data. They act as prompts to the recording of important information of assistance in interpreting galloping events, guiding the implementation of remedial measures, collating the costs of galloping and advancing scientific understanding and theories. In these respects, they should repay the time

and effort taken by the utility concerned in acquiring the information. Perhaps the greatest value would be in collating them internationally since the number of well-documented galloping events from any one Country is, in most cases, small. This can be achieved through the Task Force on Galloping. If completed Forms are returned by utilities direct to a National Member of the Task Force or the National Member of Study Committee 22, then an annual compilation could be produced and distributed. This would maximize the availability and usefulness of a limited resource and improve our chances of overcoming this most resilient of problems.

**Study Committee 22, Working Group 11, Task Force 2**  
**GUIDE TO VIBRATION MEASUREMENTS ON OVERHEAD LINES**  
**Electra No. 163 (1995)**

Wind induced, aeolian conductor vibration is the major cause of fatigue damage of overhead line conductors. This guide applies to those measurements carried out on conductors of overhead lines, excited under natural wind conditions, in order to assess their vibration activity and in particular to obtain bending amplitude measurements, which have become generally accepted in the industry.

The objective of this guide is to provide recommendations on the measurement procedure, assistance for the requirements of measuring equipment and standardization of data acquisition and presentation of results. Different approaches to the evaluation of the measurements are also presented together with a worked-out example. The guide includes the following sections:

1. Aim and objectives of field vibration measurements. Aims are to obtain data that allow decisions for the specific line and contribute to create databases. Several operative and research objectives are listed.
2. Conductor fatigue mechanism. This is only a brief review of the mechanisms, locations and main factors that characterize this phenomenon.
3. Measurement procedure. This includes sub-sections on choice of measurement procedure, choice and duration of test period, recommendation for vibration measurement instruments, sources of possible measurement inaccuracies and data reduction and storage.
4. Evaluation of field measurements. This includes sub-sections on conversion of bending amplitude to bending stress or strain, commonly used fatigue limits, and risk assessment.
5. Example. This section shows how to prepare a complete Evaluation Report, using data from actual field measurements on an ACSR conductor.

**Study Committee 22, Working Group 11, Task Force 03**  
**RESULTS OF THE QUESTIONNAIRE : "FITTINGS FOR FIBRE OPTIC CABLES ON OVERHEAD LINES"**  
**Electra No. 165 (1996)**

The immunity of fibre optic cable to electromagnetic interference is a major advantage for its use in power transmission systems and has resulted in the development of three basic systems:

- Optical Ground Wire (OPGW)
- All-dielectric Self Supporting Cable (ADSS)
- Optical Attached cable (OPAC)

The task force prepared a questionnaire with the purpose of gathering information about the experience of utilities around the world concerning the use of the above fibre optic cables.

The responses to the questionnaire represent a small sample of utilities in the world. The information given reflects the actual and planned installations as at 1991. It was found that OPGW was used for long span, higher voltage applications. The tension fittings used on OPGW are primarily helical dead-ends. The suspensions used were almost completely AGS and the dampers were mostly the Stockbridge types. Most OPGW is grounded by various methods. ADSS is mainly used in shorter spans and lower voltage. Tension fittings are predominantly of the helical type. The suspension fittings are either Armour Grip Suspension or special dielectric supports with an elastic cushion insert around the cable. The dampers are primarily spiral vibration dampers. Since the Attached cable is mainly used on earth wire, it can be installed in any application. Overlay with no in-span fittings accounts for the majority of attached systems.

It would appear that the experience at the three different cable types and their installation is predominantly trouble free with few problems experienced with cables and fittings.

**Study Committee 22, Working Group 11, Task Force 03**

**GUIDE TO FITTINGS FOR OPTICAL CABLES ON TRANSMISSION LINES - PART 1 - SELECTION AND USE**

**Electra No. 176 (1998)**

The objective of Part 1 of this guide is to provide recommendations for the selection and use of fittings for optical cables on overhead transmission lines. Part 2 will recommend testing procedures for these fittings. The cable types covered in this guide are:

- Optical Ground Wire (OPGW). A stranded metallic cable incorporating optical fibres designed to be used as a ground wire
- Optical Conductor (OPPC also known as OPCON) A stranded metallic cable incorporating optical fibres designed to be used as a phase conductor
- All-dielectric Self-Supporting Cable (ADSS). A cable of metal free construction incorporating optical fibres to be installed between tower anchor points physically separated and independent from the power line.
- Attached. An all-dielectric optical fibre cable supported by the ground wire or phase conductor.

The optical cables and fittings are a system. The fittings must be compatible with the cable to ensure that the system will survive the operating environment for the design life. Throughout this report the fittings of each cable are discussed separately, considering the general requirements and the different loads the fittings must be able to withstand without causing damage to the cable, both optically and mechanically, during its design life. As with most fittings in the power industry, the design life should typically be more than 30 years. Some fittings for optical cables, such as tension fittings, suspension fittings, aeolian vibration dampers and grounding connectors are also shown in Appendix A.

**Study Committee 22, Working Group 11, Task Force 01**

**MODELLING OF AEOLIAN VIBRATION OF SINGLE CONDUCTORS: ASSESSMENT OF THE TECHNOLOGY**

**Electra No. 181 (1998)**

Reliable transmission line design requires that vibration of the conductors due to wind is controlled below critical levels to avoid fatigue damage. Approaches available to guide this process can be pragmatic through design rules based on past experience. Also, conditions can be assessed through measurements on existing lines, using special measuring instruments. This paper deals with an analytical approach that may be used to investigate alternatives in the design or redesign process. In particular, this paper describes the Energy Balance Principle (EBP) which is used to estimate an upper bound to the expected vibratory motions, gives examples of measured wind and conductor data, and provides some comparisons with available field measurements. As the first step in defining the dynamic behaviour of single conductors subjected to aeolian vibration, studies have been made of undamped single conductors exposed to low turbulence wind. The paper shows, that through predictions of aeolian vibration level in operating lines, obtained by using the EBP method and the various available databases, it is possible to obtain a good reproduction of the frequency range and of the distribution of vibration amplitudes with frequency. The predicted amplitude level in some cases is quite close to the measured, but in some other cases is quite different, due to several reasons discussed in this paper. In practice, assessment of the aeolian vibration condition of particular lines, with conductors whose mechanical properties are poorly defined, or with special terrain conditions, may require field measurements. Techniques to perform such measurements have been described in Electra No. 163.

**Study Committee 22, Working Group 11, Task Force 04**

**SAFE DESIGN TENSION WITH RESPECT TO AEOLIAN VIBRATIONS - PART 1: SINGLE UNPROTECTED CONDUCTORS**

**Electra No. 186 (1999)**

It is well known that stranded conductors get more vulnerable to Aeolian vibrations as tension is increased. Hence, there is a need to set an upper limit to conductor tension, which prevails for significant periods of time. This report deals with that issue, as applied to single unprotected conductors of the most common types. The Task Force is actually working on a second part aiming at single damped conductors. Guidance to such safe design tension with respect to aeolian vibrations was given in 1962 by the so-called EDS Panel of CIGRE. However, the EDS parameter as suggested at that time and expressed as a percentage of the conductor breaking strength, proved with accumulating experience not to be appropriate.

The maximum safe design tensions with respect to Aeolian vibrations of undamped and unarmored conductors, as recommended by the Task Force, are shown in this paper as a function of terrain category. The ratio of tension  $H$  in the span to conductor weight per unit length  $w$  is proposed as the tension parameter. The tension  $H$  refers to initial horizontal tension, before wind and ice loading and before creep,

at the average temperature of the coldest month on the site of the line. Terrains have been divided into four categories according to general characteristics. The safe tension parameter H/w range from 1000 in flat terrain with no obstacles (Category 1) to 1450 in terrain with trees and buildings (Category 4). Recommended safe tensions apply to all conventional round stranded conductors using aluminium and/or aluminium alloys and should be suitable most of the times. However, special situations such as extra-long spans, spans exposed to pollutants, spans often covered by ice, spans operated at high temperature, require specific attention. Use of armour rods or special supporting devices may justify higher design tensions.

#### **Study Committee 22, Working Group 11, Task Force 03**

#### **GUIDE TO FITTINGS FOR OPTICAL CABLES ON TRANSMISSION LINES – PART 2A – TESTING PROCEDURES - Optical Ground Wire fittings and Optical Phase Conductor Fittings**

**Electra No. 188 (2000)**

The objective of this document is to provide a reference guide for the type testing procedures of fittings that are in direct contact with optical cables on overhead transmission lines. Part 1 of this guide provided recommendations for the selection and use of fittings for optical cables on overhead transmission lines. This paper (Part 2A) provides recommendations for the type testing procedures of fittings for Optical Ground Wire (OPGW) and Optical Phase Conductor (OPPC also known as OPCON). Part 2B of this guide will provide recommendations for the type testing procedures of fittings for All Dielectric Self Supporting Cable (ADSS) and Optical Attached Cable (OPAC).

All fittings should be designed for a service life at least equivalent to that of the cable under all known service conditions. Material and finishing should be suitable for an operating temperature range of minus 40°C to plus 70°C. For specific applications the lower temperature limit may be changed, by the customer, to minus 60°C.

The optical cables and fittings are a system and it is essential that the fittings and the cable be tested together. Each type of cable and the performance requirements of its fittings are discussed separately. In particular, the recommended tests and relevant arrangements, the optical signal monitoring, the loading sequence and the fatigue tests are discussed. The acceptance criteria refer to the loads the fittings should be able to withstand without causing damage to the cable, both optically and mechanically, or impair the fatigue performance of the cable during its design life. Where specified, the tests should be performed with an optical signal in the cable, and the test criterion is practically that no increase in the optical attenuation due to fittings occurs. OPCON cables are also considered for RIV and Corona tests. Where applicable the fittings should conform to the requirements of IEC Standard 61284 "Requirements and tests for overhead line fittings".

#### **Study Committee 22, Working Group 11, Task Force on Galloping**

#### **REVIEW OF GALLOPING CONTROL METHODS**

**Electra No. 191 (2000)**

This review is based on a collection of contributions from various galloping specialists, coordinated by Convenors of the CIGRE Task Force on Galloping. This report has two main sections, namely "retrofit" systems and "design" influences.

Retrofit systems are installed as accessories to an existing line, using the existing towers, fittings and conductors. Most of them influence the mechanical or aerodynamic characteristics of the iced conductor system, but some ice removal devices are also mentioned, which contribute to the control of galloping. Retrofit systems are: interphase spacers, torsional control devices, aerodynamic control devices, ice removal systems and others.

Design influences cover the design aspects of towers, conductors, fittings and bundle configurations. Design influences include: freely rotating bundled conductors, anti-galloping conductors, fitting and bundle arrangements. The increase of phase clearance to prevent flashover during galloping, which is a common practice, is not discussed.

Subsections describe the various approaches including, in addition to the theoretical operating principle, some practical data (condition of use, extent of use, country of use) and references. All data are grouped into summary tables, one for each subsection. The main sections deal with control methods that are in current use. However, a short survey of discontinued methods has been added in a further section, so that their shortcomings are documented and those that have proved to be unsatisfactory are not pursued again.

No economic analysis of galloping control methods has been conducted, as any commercial aspects are avoided in this review.

**Study Committee 22, Working Group 11, Task Force 03**

**GUIDE TO FITTINGS FOR OPTICAL CABLES ON TRANSMISSION LINES - PART 2B – TESTING PROCEDURE – All Dielectric Self Supporting Cable Fittings and Optical Attached Cable Fittings**

**Electra No. 191 (2000)**

The objective of this document is to provide a reference guide for the type testing procedures of fittings that are in direct contact with optical cables on overhead transmission lines. Part 1 of this guide provided recommendations for the selection and use of fittings for optical cables on overhead transmission lines. Part 2A of this guide provided recommendations for the type testing of fittings for Optical Ground Wire (OPGW) and Optical Phase Conductor (OPPC). This Part 2B deals with fittings for All Dielectric Self Supporting cables (ADSS) and for Optical Attached Cables (OPAC)

All fittings should be designed for a service life at least equivalent to that of the cable under all known service conditions. Material and finishing should be suitable for an operating temperature range of minus 40°C to plus 70°C. For specific applications the lower temperature limit may be changed, by the customer, to minus 60°C.

The optical cables and fittings are a system and it is essential that the fittings and the cable be tested together. Each type of cable and the performance requirements of its fittings are discussed separately. In particular, the recommended tests and relevant arrangements, the optical signal monitoring, the loading sequence and the fatigue tests are discussed. The acceptance criteria refer to the loads the fittings should be able to withstand without causing damage to the cable, both optically and mechanically, or impair the fatigue performance of the cable during its design life. Where specified, the tests should be performed with an optical signal in the cable and the test criterion is practically no increase in the optical attenuation due to fittings. For OPAC cables, installed on phase conductors, also RIV and Corona tests should be performed. Where applicable the fittings should conform to the requirements of IEC Standard 61284 "Requirements and tests for overhead line fittings".

**Study Committee 22, Working Group 11, Task Force 04**

**SAFE DESIGN TENSION WITH RESPECT TO AEOLIAN VIBRATIONS – PART 2 - DAMPED SINGLE CONDUCTORS**

**Electra No. 198 (2001)**

It is well known that stranded conductors get more vulnerable to Aeolian vibrations as tension is increased. Hence, there is a need to set an upper limit to conductor tension that prevails for significant periods of time. The Task Force already produced the first part of this guide that deals with single unprotected conductors (see Electra No. 186). The present report, aiming at single conductors damped by means of Stockbridge-type dampers, constitutes the second part of the guide. It provides guidance to conductor safe design tension with respect to Aeolian vibrations in terms of two parameters: the tension parameter  $H/w$ , the ratio of horizontal tension  $H$  in the span to conductor weight  $w$  per unit length, and the span parameter,  $LD/m$ , the ratio of actual span length  $L$  times conductor diameter  $D$  to conductor mass  $m$  per unit length. The tension  $H$  refers to initial horizontal tension before wind and ice loading and before creep, at the average temperature of the coldest month on the site of the line. The Task Force recommendations are depicted in the form of four similar graphs, each one associated with a particular terrain category described in the corresponding legend. Each graph shows three distinct zones:

- The Basic Safe Design Zone – No Damping applies to undamped and unarmored single conductors, as already shown in the Part 1 of this report. This zone is defined in terms of the  $H/w$  parameter only.
- The Safe Design Zone – Span End Damping where full protection of single conductors against Aeolian vibrations is feasible by means of one or more Stockbridge-type damper(s) set up at span extremities.
- The Special Application Zone, in which Aeolian vibrations may or may not be a constraint and line designers should determine the availability of adequate protection before finalizing the design.

Recommended safe tensions apply to all conventional round stranded conductors using aluminium and/or aluminium alloy and to dampers of Stockbridge-type only. Use of armour rods or special supporting devices may justify higher design tensions.

**Study Committee B2 (22), Working Group 11, Task Force 05**

**STATE OF THE ART SURVEY ON SPACER AND SPACER DAMPERS – PART1 – GENERAL DESCRIPTION**

**Electra No. 209 (2003)**

The use of multi-conductor bundles in high voltage overhead transmission lines has been established for several decades. Conductor spacers rapidly became important pieces of hardware aimed at maintaining the geometry of the bundles to meet the requirements of electrical performance. However, their role soon evolved as a more important component of a complex electro-mechanical system exposed to the natural environment, requiring that their construction, installation and location along the span be properly specified. Spacer dampers have been developed in a variety of configurations and designs, making ingenious use of a

number of different materials. This paper is the first part of a State of the Art survey and presents the general description of spacers and spacer dampers. Part 2 and Part 3 of this survey will develop the design aspects of spacers and spacer dampers and will report on present field experience.

This paper covers the following topics:

- Number and location of the spacers, which are defined mainly in respect to wind-excited vibrations but also considering the short circuit forces and the bundle twist due to ice loads.
- Types of spacers. This section gives a classification and description of the types of spacers used in bundled conductors, such as rigid spacers, articulated spacers, flexible spacers and spacer dampers.
- Materials used in spacers. This section gives a review of the materials commonly employed in spacers, the material requirements and the selection criteria.
- Clamping systems. It is very important that spacer clamps be able to provide a safe, reliable long-term grip. This section presents the requirements of the spacer clamping systems and the design characteristics of the most common types of clamps that are: cantilever clamps, opposed-hinge clamps, elastomer-lined clamps and helically-attached clamps.

#### **Study Committee B2 (22), Working Group 11, Task Force 05**

#### **STATE OF THE ART SURVEY ON SPACER AND SPACER DAMPERS – PART2 – TECHNICAL ASPECTS**

In Part 1 of this survey, a general description of the mechanical system formed by conductor bundles and spacers or spacer dampers was presented. In this paper (Part 2), more technical aspects are considered. The design characteristics for spacers and spacer dampers are reviewed. Mechanical characteristics are presented with reference to clamp grip, degrees of articulation and short circuit resistance. Dynamic characteristics of the various types of spacers are discussed in relation to the vibration modes of the bundles produced by wake induced oscillation and aeolian vibration. The electrical characteristics involving the conductivity of the spacer and spacer damper components and the corona and RIV performance of the same devices are examined. Moreover, some considerations on how to resist the environmental attack and to avoid audible noise are provided. Further, the methods developed for the assessment of the mechanical, electrical and environmental characteristics of the spacers are discussed. Field measurement methods are presented to assess the actual dynamic behaviour of conductor bundles. Moreover, a brief summary of the analytical basis and the computational methods developed to date to predict bundle response and to assist in the interpretation of field measurements, highlight the complexity of the problem and the importance of continuing to pursue better solution for the control of conductor bundle motions.

The survey "Sample of previous specifications", provided in Annex A, is a condensed summary of existing specifications for spacer and spacer dampers worldwide.

Part 3 will report on current practice, field experience and on the results of a survey of utilities' experience with the use of spacers and spacer dampers.

#### **Study Committee B2 (22), Working Group 11, Task Force 05**

#### **STATE OF THE ART SURVEY ON SPACER AND SPACER DAMPERS – PART3 – EXPERIENCE WITH CURRENT PRACTICE**

Two previous papers, Part 1 and Part 2 of this survey presented a general description of a conductor bundle system and some important technical aspects related to the design of spacers and spacer dampers. Part 3 contains important contributions based on the experience of both the TF5 experts and the utilities worldwide. The latter was obtained by means of a questionnaire titled "Survey on Damage to Spacer and Spacer Dampers and/or Conductors in Bundled Conductor Lines" prepared by the SC22-WG11-TF5. The questionnaire was circulated all over the world and a total of 66 replies from 19 countries were received. Unfortunately, several countries operating long EHV transmission lines (e.g. Russia, India, China) did not respond. However, sufficient replies were received to yield some useful information. The responses indicate that the twin bundle lines are the most common but have the least incidence of problems, whereas quad bundles are second in order of usage but have the highest incidence of problems. Triple bundles are the least used but are second in order of problems. Flexible and articulated spacers are the most employed, probably for the predominance of twin bundles where they are of common use. Spacer dampers are close second, while rigid spacers have by far the lowest application. The average time to spacer/spacer damper failure is about 10 years and its primary cause appears to be a combination of high-level conductor vibration and oscillation together with poor spacer performance and/or probably incorrect installation. The majority of the problems occur at the clamp/conductor interface where conductor failure due to metal-to-metal clamp loosening and conductor corrosion due to elastomer lined clamps have been reported.

This field experience, if used judiciously with the technical aspects and design characteristics presented in the two previous parts, should enable the transmission line engineers to correctly evaluate different spacer damper systems for adequate protection of a line.

**Study Committee 22, Working Group 04**  
**ENDURANCE CAPABILITY OF CONDUCTORS – Final report**  
**CIGRE Brochure (July 1988)**

For the operation and design of transmission lines, a reliable determination of conductor lifetime is a necessity. Such is made possible by means of the CIGRE-WG 22-04-Method described in this report, which since 1979 has been applied all over the world for maintenance, research and rehabilitation of transmission lines. Wind-induced conductor vibrations may cause wire fractures, mainly in the inner layers of the conductor, which often are not discovered until after several years of service, which in most of the cases is too late. The main subject of this report covers the measures to recognize early and to avoid dangerous conductor vibrations. To assess the expected total endurance of the conductor, three things have to be done:

- Firstly, the conductor vibration has to be recorded for a representative period, in term of cable deflection (IEEE Method) or the strain (stress) amplitudes at the clamp. For this task, test stations and modern vibration recorders are recommended.
- Secondly, a representation of the materials response has to be used. Alternatively, the S-N (Wholer) curves of the conductor can be employed.
- Thirdly, the application of a suitable damage accumulation theory is then necessary to connect both evaluations and to assess the conductor endurance (Miner Rule).

In this report, causes, consequences and methods of diagnosis are described, and a short retrospective look is taken at the efforts, which have been made to solve the problem. Today state of the art methods to determine the remaining lifetime of conductors and to predict the effect of vibration damping measures leading to the design of vibration-safe transmission lines, are also outlined. Finally, a method for the estimation of conductor lifetime based upon danger factors is proposed.

## APPENDIX 1

### A BRIEF HISTORY OF WGs 01 AND 04

Transmission line conductors and their fittings have been on the agendas' of CIGRE meetings since 1926. In the foreground were CIGRE reports of damages on conductors (inter alia 1933 No126; 1935 No 204 and 214).

Since 1953, the CSC Committee 6 (Bare Conductors and Mechanical Calculation of Overhead Lines) with the first EDS panel, the WG02 on dampers, WG03 on spacers and WG 05 on creep behaviour were working on these problems. EDS recommendations were subsequently presented (CIGRE paper CSC 6-61-3).

By 1962, some doubts about the validity of the EDS recommendations had been published (CIGRE paper CSC 6-62-5). This paper sought representative values of aluminium stresses for conductors with different AL./Steel ratios. This was an attempt to consider the creep effect on the stresses in aluminium strands and the fatigue limits (WG05 report ELECTRA No 75 refers). This was published again in extracts in ELECTRA 1979 No 63 -Appendix 1 and 2.

As a result, **WG01** (Vibration Theory), **WG02** (Dampers and Fittings) and **WG04** (Endurance Capability of Conductors) were established in 1965.

W01 sought a theoretical solution to the behaviour of the vibrating conductor with the EBP (Energy Balance Principle) in the context of the Strouhal relationship. Vibration frequencies and amplitudes were thereby calculated.

WG01 and WG02 held a number of joint meetings because of the closely related nature of their respective tasks. In 1971, WG02 merged with WG01 and a Spacer Panel and Fittings and Accessories Task Force were subsequently established within the newly expanded WG01.

WG04 worked in three distinct areas:-

Firstly, laboratory fatigue tests were conducted in different countries, especially in Sweden, to investigate the lifetime of conductors characterized by the number of cycles to cause breakage of 3 strands under different static and dynamic stresses in the aluminium strands. The stresses and the number of cycles accumulated are the main influences on the lifetime of a conductor.

Secondly, field measurements were carried out on transmission lines to obtain the amplitude/frequency matrix of the vibrating conductor during a test period of about 2 months. This period was considered to be a representative basis for lifetime calculations, at least for most countries. The measurements were usually made using the bending amplitude method, (IEEE Report January 1966) but there were some cases of direct stress measurements with strain gauges on the outer layer of aluminium strands.

Thirdly, the survey of service failures was renewed by a questionnaire in 1975. 52 utilities replied to the questionnaire and of these, 28 reported significant damage. Aeolian vibration accounted for 40 incidents, galloping for 12 incidents and sub-conductor oscillation for 4 only incidents. The summary led to the statement: 'that aeolian vibration is undoubtedly the most unpredictable factor, which is mainly influenced by the terrain, i.e. by the characteristic of the wind, which changes with location and time along the line'.

1972, CSC6 and CSC7 (Towers and Foundations) were merged to form CSC22 (now SCB2) and the WG's of CSC 6 continued with their tasks without interruption.

WG04 published the "Guide for Endurance Tests of Conductors Inside Clamps", ELECTRA 1985 No100 and the main report "Recommendation for the Evaluation of the Lifetime of Transmission Line Conductors" ELECTRA 1979 No 63. Field measurements were published in CIGRE Reports 1968 No 22-07 and 1972 No 22-05. After 20 challenging and successful years, WG 04 finished its work in 1985

Complementary to the WG04 reports, TF 02 of WG11 (1986-1995) subsequently presented its "Guide to Vibration Measurements on Overhead Lines" ELECTRA 1995 No 163.

**Walter Buckner      Magnar Ervik**

**August 2003**

## APPENDIX 2

**1987 AND ALL THAT**  
OR  
**The Chronology of CIGRÉ SC22 WG11**  
**"Mechanical Behaviour of Conductors and Fittings"**  
**From December 1987 to May 2003**

by D.G. Havard

<b><u>Meeting No. 1</u></b>	<b>Dec 1987</b>	<b>Stockholm, Sweden</b>	<b>Host: Rolf Ruritz</b>
Established WG11	"Mechanical Behaviour of Conductors and Fittings"		
Convenor WG11			Rolf Ruritz
Secretary WG11			Bill Kyte
Established TF1	"Vibration Principles"		
Convenor TF1			Francesco Tavano
Established TF2	"Vibration Measurements"		
Convenor TF2			Helmut Strub
Established TF3	"Fittings"		
Convenor TF3			Arne Berg
Established TFG	"Galloping"		
Convenor TFG			Mike Tunstall
Secretary TFG			Dave Havard
<b><u>Meeting No. 2</u></b>	<b>May 1988</b>	<b>Athens, Greece</b>	<b>Host: Konstantin Papailiou</b>
<b><u>Meeting No. 3</u></b>	<b>Aug 1988</b>	<b>Paris, France</b>	<b>Host: D. Feldmann</b>
<b><u>Meeting No. 4</u></b>	<b>May 1989</b>	<b>Brighton, England</b>	<b>Host: Bill Kyte</b>
	Bill Kyte died Aug 31 1989		
<b><u>Meeting No. 5</u></b>	<b>Oct 1989</b>	<b>Sarajevo, Jugoslavia</b>	<b>Host: D Muftic</b>
Acting Secretary WG11			Tom Smart
<b><u>Meeting No. 6</u></b>	<b>June 1990</b>	<b>Gaustablikk, Norway</b>	
			<b>Host: Arne Berg</b>
New Secretary WG11			Dave Havard
New Secretary TFG			Henning Øbro
<b><u>Meeting No. 7</u></b>	<b>Sept 1990</b>	<b>Paris, France</b>	
<b><u>Meeting No. 8</u></b>	<b>May 1991</b>	<b>Oslo, Norway</b>	<b>Host: Arne Berg</b>

<b><u>Meeting No. 9</u></b>	<b>Sept 1991</b>	<b>Fort Worth, USA</b>	<b>Host: Joe Pohlman</b>
	Arne Berg died Dec 1991		
<b><u>Meeting No. 10</u></b>	<b>May 1992</b>	<b>Malaga, Spain</b>	<b>Host: Enrique del Pozo</b>
	New Convenor TF3 Tom Smart		
<b><u>Meeting No. 11</u></b>	<b>Sept 1992</b>	<b>Paris, France</b>	
	New Convenor WG11		Dave Havard
	New Secretary WG11		David Hearnshaw
	Established TF4	"Design Guide on Conductor Tensions"	
	Convenor TF4		Claude Hardy
	Secretary TF4		Hans-Jörg Krispin
	Publication:		
	"Results of Questionnaire on Interphase Spacers"		
	ELECTRA Vol 143, Aug 1992:		Arne Berg/Tom Smart
<b><u>Meeting No. 12</u></b>	<b>May 1993</b>	<b>Canterbury, UK</b>	<b>Host: Mike Tunstall</b>
<b><u>Meeting No. 13</u></b>	<b>Sept 1993</b>	<b>Montreal, Canada</b>	<b>Host: Claude Hardy</b>
<b><u>Meeting No. 14</u></b>	<b>Apr 1994</b>	<b>Malmö, Sweden</b>	<b>Host: Christopher Schlyter</b>
<b><u>Meeting No. 15</u></b>	<b>Sep 1994</b>	<b>Evreux, France</b>	<b>Host: Philippe Mouchard</b>
	TF2 Closed		
<b><u>Meeting No. 16</u></b>	<b>Apr 1995</b>	<b>Pleinfeld, Germany</b>	<b>Host: Johannes Schmidt</b>
	New Convenor TF1		Giorgio Diana
	New Secretary TF1		Louis Cloutier
	Established TF5	"Spacer-Dampers"	
	Convenor TF5		Louis Cloutier
	Secretary TF5		Maurice Murphy
<b><u>Meeting No. 17</u></b>	<b>Sept 1995</b>	<b>Madrid, Spain</b>	<b>Host: Francisco Morentin</b>
	Publications:		
	"Field Observations of Overhead Line Galloping: Galloping Observation Forms"		
	ELECTRA, Vol. 162, Oct 1995		Mike Tunstall
	"Guide to Vibration Measurement on Overhead Lines"		
	ELECTRA, Vol 163, Dec 1995		Helmut Strub

**Meeting No. 18**      **Apr 1996**      **Santa Margherita Ligure, Italy**      **Host: Giorgio Diana**

“Aeolus Awards” introduced and presented to:  
Rolf Ruritz as founding convenor of WG11  
Giorgio Diana for hosting the meeting

Publication:

"Results of Questionnaire: "Fittings for Fibre Optic Cables on Overhead Lines"  
ELECTRA, Vol. 165, Apr 1996      Tom Smart

**Meeting No. 19**      **Aug 1996**      **Paris, France**      **Host: Philippe Mouchard**  
New Convenor of TFG      Marc Wolfs  
New Secretary of TFG      David Sunkle

“Aeolus Awards” presented to:  
Francesco Tavano for convenorship of TF1  
Helmut Strub for convenorship of TF2 and ELECTRA report  
Tom Smart for ELECTRA report

**Meeting No. 20**      **Apr 1997**      **Porto Rio, Greece**      **Host: Konstantin Papailiou**  
New Secretary of TF5      Rolf Kleveborn

“Aeolus Awards” presented to:  
Lotar Moecks for long service representing Germany  
Mike Tunstall as convenor of TFG and ELECTRA report  
Konstantin Papailiou for hosting the meeting

**Meeting No. 21**      **Oct 1997**      **Sendai, Japan**      **Host: Masataka Mito**

“Aeolus Award” presented to:  
Masataka Mito for hosting the meeting

Publication:

"Guide to Fittings for Fibre Optic Cables on Transmission Lines, Part 1 – Selection and Use"  
ELECTRA, Vol. 176, Feb 1998      Tom Smart

**Meeting No. 22**      **Apr 1998**      **Graz, Austria**      **Host: Wolfgang Troppauer**  
New Secretary of TF3:      Soren Damsgaard Mikkelsen

“Aeolus Awards” presented to:  
Tom Smart for ELECTRA report  
Wolfgang Troppauer for hosting the meeting

**Meeting No. 23**      **Aug 1998**      **Avignon, France**      **Host: Philippe Mouchard**

“Aeolus Awards” presented to:  
Giorgio Diana for ELECTRA report  
Philippe Mouchard for hosting meetings in France

**Meeting No. 24**      **Apr 1999**      **Chester, UK**      **Host: Tom Smart**  
 New Convenor of WG11      Konstantin Papailiou  
 New Secretary of WG11:      Alessandra Manenti Diana  
 New Secretary of TF3      Michel St. Louis  
 WG11 sets up as first WG in SC22 its own web-site [www.regio.com.ch/acolus](http://www.regio.com.ch/acolus)  
 "Aeolus Awards" presented to:  
 David Havard for Convenor of WG11 for 6 years  
 Walter Bückner for long term Convenor of WG04  
 David Hearnshaw for Secretary of WG11 for 6 years  
 Marc Wolfs for Convenor of TFG  
 Publication:  
 "Aeolian Vibrations of Single Conductors: Assessment of the Technology",  
 ELECTRA, Vol. 181, December 1998      Giorgio Diana

**Meeting No. 25**      **Oct 1999**      **Sydney, Australia**      **Host: Philip Dulhunty**  
 New Convenor for TFG      Jean-Louis Lilien  
 "Aeolus Awards" presented to:  
 Philip Dulhunty for hosting the meeting.  
 Magnar Ervik as long term Convenor of WG 01.  
 Claude Hardy as Convenor of TF4 and ELECTRA Publication

**Meeting No. 26**      **May 2000**      **Kolding, Denmark**      **Host: Soren Damsgaard**  
**Mikkelsen**  
 New Convenor for TF3      David Sunkle  
 New Secretary for TFG      Pierre Van Dyke  
 Publications:  
 "Safe Design Tension with respect to Aeolian Vibration– Part 1: Single Unprotected  
 Conductors",  
 ELECTRA, Vol. 186 Oct 1999      Claude Hardy  
 "Guide to Fittings for Optical Cables on Transmission Lines, Part 2A : Testing Procedures "  
 ELECTRA, Vol. 188, Feb 2000      Tom Smart  
 "Aeolus Awards" presented to:  
 Soren Damsgaard Mikkelsen and Henning Oebro for hosting the meeting

**Meeting No. 27**      **Aug 2000**      **Evreux, France**      **Host: Philippe Mouchard**  
 Closure of TF4  
 Publications:  
 "Review of Galloping Control Methods"  
 ELECTRA , Vol. 191 Aug 2000      Marc Wolfs  
 "Guide to Fittings for Optical Cables on Transmission Lines, Part 2B :      Testing  
 Procedures for non-metallic cables"  
 ELECTRA, Vol. 191, Aug 2000      Tom Smart



**Meeting No 33**      **Sept, 2003**      **Edinburgh, UK**      **Hosts: Sven Hoffman**  
**Mike Tunstall**  
Acting Secretary for this meeting of WG11      David Hearnshaw  
New Convenor of WG11 confirmed (Paris 2004)      David Hearnshaw  
Secretary of TF3 (retiring)      Michel St Louis  
Secretary of TF3 (designate)      Peter Dulhunty  
Thematic Brochure completed      David Hearnshaw  
Peter Dulhunty

“Aeolus Awards” presented to:  
Sven Hoffman & Mike Tunstall for hosting the meeting  
Michel St Louis for his contribution to TF3  
Bernard Dalle for his contribution to SCB2

Publication:

“State of the Art Survey on Spacers and Spacer Dampers, Part 1 General Description”  
ELECTRA, VOL 209 August 2003      Louis Cloutier