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INTERNATIONAL STANDARD

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colour inside

Overhead lines – Methods for testing self-damping characteristics of conductors

Lignes électriques aériennes – Méthodes d'essai des caractéristiques d'auto-amortissement des conducteurs

IEC 62567:2013

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OVERHEAD LINES – METHODS FOR TESTING SELF-DAMPING CHARACTERISTICS OF CONDUCTORS

FOREWORD

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The text of this standard is based on the following documents:

FDIS	Report on voting
7/629/FDIS	7/630/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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INTRODUCTION

Conductor self-damping is a physical characteristic of the conductor that defines its capacity to dissipate energy internally while vibrating. For conventional stranded conductors, energy dissipation can be attributed partly to inelastic effects within the body of the wires (hysteresis damping at the molecular level) but mostly to frictional damping, due to small relative movements between overlapping individual wires, as the conductor flexes with the vibration wave shape.

Self-damping capacity is an important characteristic of the conductors for overhead transmission lines. This parameter is a principal factor in determining the response of a conductor to alternating forces induced by the wind.

As the conductor self-damping is generally not specified by the manufacturer, it can be determined through measurements performed on a laboratory test span. Semi-empirical methods to estimate the self-damping parameters of untested conventional stranded conductors are also available but often lead to different results. Further, a great variety of new conductor types is increasingly used on transmission lines and some of them may have self-damping characteristics and mechanisms different from the conventional stranded conductors.

A “Guide on conductor self-damping measurements” was prepared jointly in the past by the IEEE Task Force on Conductor Vibration and CIGRE SC22 WG01, to promote uniformity in measuring procedures. The Guide was published by IEEE as Std. 563-1978 and also by CIGRE in Electra n°62-1979.

Three main methods are recognized in the above documents and divided into two main categories which are usually referred to as the "forced vibration" and "free vibration" methods.

The first forced vibration method is the “Power [Test] Method” in which the conductor is forced into resonant vibrations, at a number of tunable harmonics, and the total power dissipated by the vibrating conductor is measured at the point of attachment to the shaker.

The second forced vibration method, known as the “Standing Wave Method” or more precisely “Inverse Standing Wave Ratio [Test] Method” (ISWR), determines the power dissipation characteristics of a conductor by the measurement of antinodal and nodal amplitudes on the span, for a number of tunable harmonics.

The free vibration method named “Decay [Test] Method” determines the power dissipation characteristics of a conductor by measuring, at a number of tunable harmonics, the decay rate of the free motion amplitude following a period of forced vibration.

Several laboratories around the world have performed conductor self-damping measurements in accordance with the above mentioned Guide. However, large disparities in self-damping predictions have been found among the results supplied by the various laboratories. The causes of these disparities have been identified into five main points:

1) The different test methods adopted for the self-damping measurements.
2) The different span end conditions set up in the various test laboratories (rigid clamps, flexure members, etc.)
3) The different types of connection between the shaker and the conductor (rigid or flexible) and the different location of the power input point along the span.
4) The different conductor conditioning before the test (creep, running in, etc.)
5) The different manufacturing processes of the conductor.

OVERHEAD LINES – METHODS FOR TESTING SELF-DAMPING CHARACTERISTICS OF CONDUCTORS

1 Scope

The scope of this Standard is to provide test procedures based on the above-mentioned documents and devoted to minimize the causes of discrepancy between test results, taking into consideration the large experience accumulated in the last 30 years by numerous test engineers and available in literature, including a CIGRE Technical Brochure specifically referring to this standard (see Bibliography).

This Standard describes the current methodologies, including apparatus, procedures and accuracies, for the measurement of conductor self-damping and for the data reduction formats. In addition, some basic guidance is also provided to inform the potential user of a given method's strengths and weaknesses.

The methodologies and procedures incorporated in this Standard are applicable only to testing on indoor laboratory spans.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-466:1990, *International Electrotechnical Vocabulary. Chapter 466: Overhead lines*

IEEE Std. 563-1978, *IEEE Guide on conductor self-damping measurements*

IEEE Std. 664-1993, *IEEE Guide for laboratory measurement of the power dissipation characteristics of aeolian vibration dampers for single conductors*

3 Terms and definitions

For the purpose of this International Standard, the definitions of the International Electrotechnical Vocabulary (IEV) apply, in particular IEC 60050-466. Those which differ or do not appear in the IEV are given below.

3.1
conductor self-damping:
the self-damping of a conductor subjected to a tensile load T is defined by the power P_{c} dissipated per unit length by the conductor vibrating in a natural mode, with a loop length $\lambda/2$, an antinode displacement amplitude Y_0 and a frequency f

3.2
node
in a vibrating conductor, nodes are the points in which the vibration amplitude is the smallest

3.3
anti-node
in a vibrating conductor, anti-nodes are the points in which the vibration amplitude is the greatest

4 Symbols and units

A	forcing point transverse acceleration, single amplitude	m/s^2
a_n	vibration amplitude at the nth node	mm
D,d	diameter of the conductor	m
δ	logarithmic decrement	
E_{diss}	total energy dissipated by the vibrating conductor	Joule
E_{kin}	total kinetic energy of the vibrating conductor	Joule
F	single amplitude exciting force	N
f	vibration frequency	Hz
h	non dimensional viscous damping coefficient	
L	free length of the test span	m
λ	wavelength	m
$\lambda/2$	loop length	m
m	conductor mass per unit length	kg/m
n	number of vibrating loops in the span	
n_c	number of vibration cycles	
n_{kj}	number of loops between loop *k* and loop *j*	
P	power dissipated by the conductor	mW
P_c	power dissipated by the conductor per unit length	mW/m
P_j	power dissipated by the conductor, measured at loop j	mW
P_k	power dissipated by the conductor, measured at loop k	mW
θ_a	phase angle between force and acceleration	deg
θ_d	phase angle between force and displacement	deg
θ_v	phase angle between force and velocity	deg
S_j	Inverse standing wave ratio (ISWR) at loop j	
S_k	Inverse standing wave ratio (ISWR) at loop k	
S_n	Inverse standing wave ratio (ISWR) at the nth loop	
T	conductor tension	N
V	forcing point transverse velocity, single amplitude	m/s
V_n	vibration velocity at the nth antinode – peak value	m/s
ω	circular frequency	rad
Y_a	single antinode amplitude at the first decay cycle	mm
Y_f	vibration single amplitude at the driving point	mm
Y_n	vibration single amplitude at the nth antinode	mm
Y_o	vibration single amplitude at antinode	mm
Y_z	single antinode amplitude at the last decay cycle	mm
$\sqrt{Tm}$	characteristic impedance of the conductor	N s/m

5 Test span arrangements

5.1 General

The laboratory test spans for conductor self-damping measurements are generally built indoor in still air areas where the variation of ambient temperature is minimal or can be suitably controlled. Ambient temperature variations up to 0,2 °C/h are considered acceptable.

The free span length L should preferably be at least ten times longer than the longest loop length used in the tests. For consistent results, a span length greater than 40m is recommended but satisfactory results can be obtained with spans in the range of 30m. For shorter spans, the influence of the termination losses and the distribution of the tensile load between the conductor strands may be critical.

The test span shall be strung between two massive blocks with a weight not lower than 10 per cent of the ultimate tensile strength of the largest conductor to be tested. Each block should be a single piece, generally made of steel reinforced concrete, and preferably be common or solidly connected with the concrete floor. The stiffness of these blocks should be as high as possible in order to minimize the losses and provide the maximum reflexion of the waves.

An example of laboratory test span layout is shown in Figure 1.

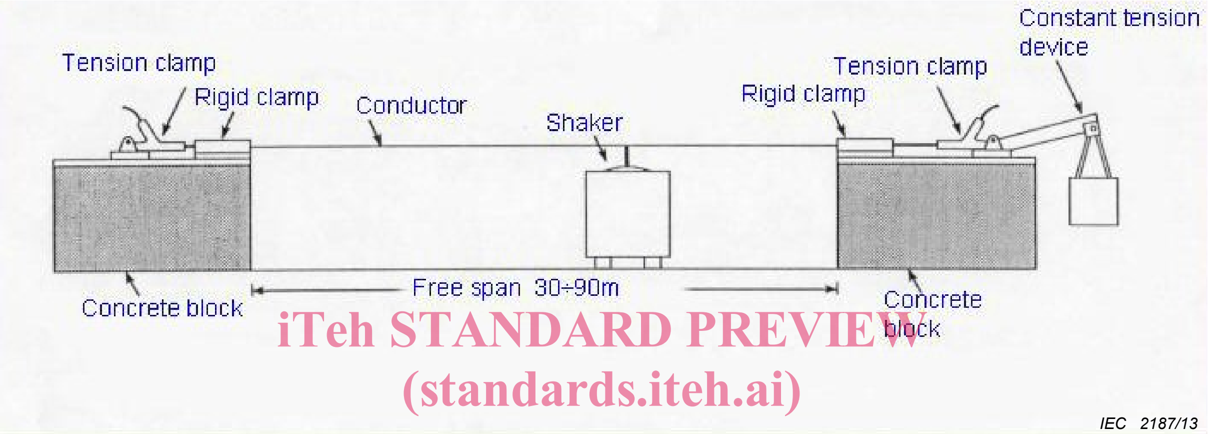

Figure 1 – Test span for conductor self-damping measurements

5.2 Span terminations

The test span should have the capability of maintaining a constant conductor tension. Hydraulic and pneumatic cylinders, springs, threaded bars and pivotal balance beams have been used successfully.

A rigid non-articulating square faced clamp similar to that shown in Figure 2 shall be used to minimize energy dissipation by the termination fixture. An example of a typical termination design is also provided in Figure 3 of IEEE Std. 563-1978. Terminating fixtures and rigid clamps shall be of sufficient stiffness to ensure that energy losses do not occur beyond the extremities of the free span.

Rigid end clamps (also called heavy clamps), equal to or up to ten times longer than the conductor diameters and with groove diameters not exceeding by more than 0,25 mm the diameter of the conductor, have given good results. Generally, the clamp groove is dimensioned for the biggest conductor to be tested and a set of sleeves is made available to accommodate smaller conductor diameters.

The rigid clamps shall not be used to maintain tension on the span. However, the rigid clamps, once closed, will retain some load. Consequently, the tension devices cannot fully control the conductor tension. Subsequent adjustments, if necessary, shall be performed only after releasing the rigid clamps.

It is very important to have a good alignment between tension clamps and rigid clamps in the horizontal direction. In the vertical direction, in order to eliminate the static bending of conductor at the rigid clamp departure, it may be necessary to incline the rigid clamps following the catenary angle. This practice, when necessary, would avoid any change in tensile load when closing or opening the clamps.


IEC 2188/13

Figure 2 – Rigid clamp

On a laboratory test span, normally, the wave shape of the end loops differs from the shape of the free loops and the end loop dissipation is greater than free loop dissipation. As the energy dissipation of the conductor is, to a first approximation, proportional to the square of its curvature, it is easy to explain the large dissipation of energy near the end of the span. The effect is more noticeable at low frequencies where the end loops constitute a higher proportion of the total number of loops. It further restricts the usefulness of very short indoor test spans.

Preference should be given to a test arrangement which would minimize energy dissipation at the span end terminations. If there is uncertainty about this, the energy should be assessed and eventually accounted for, unless using the ISWR method.

The termination losses may be minimized by terminating the conductor by a flexure member, such as a wide, flat bar of sufficient strength to accommodate the span tension but also flexible enough in the vertical direction to allow it to bend readily and to avoid bending the conductor through a sharp radius of curvature where it would normally enter the clamp. This procedure has the undesirable effect, though, of including the end termination in the test span. An example of flexible cantilever is provided in Figure 4 of IEEE Std. 563-1978.

5.3 Shaker and vibration control system

The vibration exciter used for these tests is generally an electro-dynamic shaker (Figure 3). Hydraulic actuators are also used.

Modal shakers having light armature and linear bearings can be used to excite resonance modes of the conductor with minimal distortion of the natural mode shape and to produce virtually zero stiffness and zero damping in the direction of the movement.

The shaker shall be able to provide a suitable sinusoidal force to the test span. The alternating movement provided by the shaker shall be simple harmonic with a distortion level of less than 5 %.

Vibration amplitude and frequency shall be controllable to an accuracy of ± 2 % and frequency shall be stable within 0,001 Hz.

IEC 2189/13

Figure 3 – Electro-dynamic shaker

The use of computers and dedicated software for the shaker control and for the data acquisition, reduction and elaboration is considered as a normal practice.

An example of the layout for the conductor self-damping measurements, fully equipped to perform the conductor self-damping measurements with the methods outlined in this standard, is shown in Figure 4.

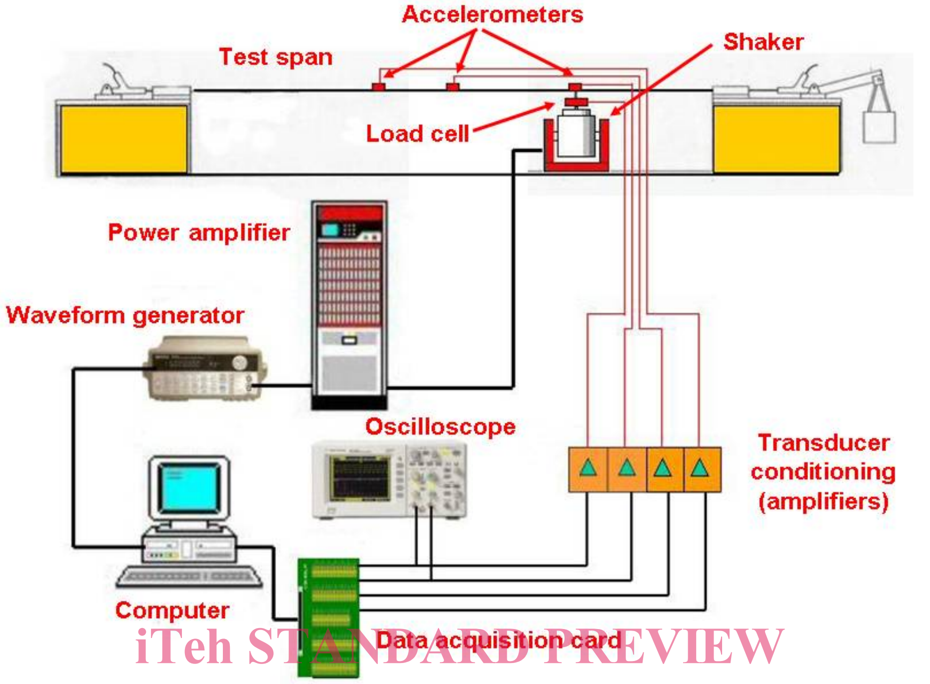

Figure 4 – Layout of a test stand for conductor self-damping measurements

5.4 Location of the shaker

The most used position of the shaker is within one of the end loops of the span, but not necessarily at an anti-node. This location also makes it possible to excite greater amplitudes than the maximum travel of the shaker even if a rigid connection between the shaker and the conductor is used.

The near end location makes it possible to excite odd numbers of loops, as well as even. Although some span symmetry may be lost due to the presence of the shaker, a centre free loop will be present for the odd loop excitations. This often makes it possible to conduct amplitude measurements within the centre loop without being forced to relocate the transducer for each frequency investigated.

The shaker should be located at a distance from the rigid clamp which is less than the calculated loop length of the span at the highest test frequency. This will ensure that whole loops will not be forced to occur between the shaker and the nearest span extremity, because this may cause erroneous test results. It is preferably to identify a location of the shaker that can be maintained unchanged for the whole test on one conductor. A wide range of conductor sizes has been tested with the shaker at a fixed distance from the end clamp of 0,8 to 1,2 m.

5.5 Connection between the shaker and the conductor under test

5.5.1 General

In the artificial excitation of the indoor test span, the armature of the shaker can be connected to the test span either rigidly or by the use of a flexible connection. In any case, the fixture shall be as light as possible in order to avoid the introduction of unwanted inertial forces and to prevent that, at the higher frequencies, the force needed to vibrate that mass plus the shaker armature will be beyond the capability of the shaker system.

To avoid distortion of the mode shape in the conductor vibration, the clamp mass must be as low as possible and, in resonance conditions, the phase between force and acceleration, at the driving point, must be as close as possible to 90 °. In this case, the force applied by the shaker has its minimum and equals the damping force. For angles different from 90 °, inertia and elastic components are also present and can give rise to distortions.

The shaker connection shall be instrumented for force and vibration level measurements. The latter is generally made using accelerometers but also velocity transducers and displacement transducer can be used.

5.5.2 Rigid connection

Rigidly fixing the shaker to the conductor (Figure 5) has a tendency to create distortion in the standing wave vibration. Care should be taken when establishing span resonance to minimize this effect.

IEC 2191/13

Figure 5 – Example of rigid connection

Using a rigid connection, the vibration exciter becomes a part of the system being measured; if the mass of the moving system within the shaker is high, conductor distortion is induced in that portion of the span where the shaker is attached.

This changes the length of the loop to which the shaker is attached and is indicative of localized inertial and damping effects. The effect of attaching the shaker to the conductor should not change the loop length in which the attachment is made by more than 10 %. An attached mass of less than 20 % of the mass per unit length of the conductor is normally satisfactory. However, this can only be achieved using modal shakers or adopting a flexible connection as described in the following paragraph. Otherwise, the ISWR method, that is not sensitive to localized effects at the shaker as well as in end loops, should be used.