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MECHANICAL DAMPERS ON OVERHEAD POWER LINES

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Abstract: *Conductors constitute important components of overhead power lines. They are characterised by low internal damping, low rigidity and low weight. Thus, they can reach high amplitudes of wind induced vibrations. As a result of such vibrations, conductors are subject to variable dynamic stresses which determine the durability of a power line. Limiting possible damage caused by wind is crucial, not only due to safety of the structure, but also for economic reasons. This paper briefly describes basic types of conductor vibration excitations caused by wind. Such aerodynamic phenomena as vortex excitation, galloping and wake induced vibrations, and selected mechanical dampers used on overhead power lines are presented.*

Keywords: Mechanical dampers, Vibration of conductors, Control of vibration.

1. Introduction

An overhead power line is a set of properly insulated conductors located next to each other on supporting structures. The crucial component of a power line is a current-leading conductor. In a power line, conductors are fixed to supporting structures with insulators. The aim of supporting structures is to support conductors and/or take their tension strength. Aluminium is generally used for designing such conductors. A typical structure of a conductor comprises a braided aluminium wire rope with steel wire core. Conductors are characterized by low rigidity, relatively low damping and low weight. Therefore, they are very susceptible to wind. One of the most important aspect, both when designing and installing power lines, is knowledge on vibration generation mechanisms. As a result of vibrations caused by wind, a conductor is subject to variable stresses which determine its durability. Amplitude and vibration frequency depend on numerous factors, such as line rated data, climatic and terrain conditions, etc. Vortex induced vibrations (aeolian vibrations), galloping and wake induced vibrations are predominant in overhead power line conductors. Reducing the level of such vibrations is very important, since undamped vibrations may lead to destruction of a conductor, equipment, power line or to a failure of a transmission network.

This paper presents basic types of overhead power line conductor vibrations caused by wind, damping of which is crucial for their safe operation and selected, effective mechanical dampers.

2. Types of vibrations

Overhead power lines are constantly subject to variable wind loads which may gradually lead to the impairment of their durability, resulting in the shortened service life. Wind forces are caused by three main types of conductor vibrations: aeolian vibrations with a frequency from 3 to 150 Hz and amplitudes lower than the conductor diameter, galloping with a frequency from 0.1 to 1 Hz and amplitudes from ± 0.1 to 1 of conductor sag, wake induced vibrations with a frequency from 0.15 to 10 Hz and amplitudes from 0.5 to 80 times the conductor diameter (Gołębiowska, 2015).

Vortex induced vibrations (aeolian vibrations). The majority of common wind induced vibrations are aeolian vibrations. These vibrations are generated as a result of vortices shed in the conductor wake under

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sustained wind of low speed from 1 to 7 m/s – they occur mainly in the vertical plane. Vibrations of conductors, both single and in a bundle, form standing waves with forced nodes and intermediate nodes located along the span at intervals depending on the frequency of free vibrations. When the conductor wind flow is laminar, alternately shedding vortices are formed in two points of the suction zone and make the conductor move perpendicularly towards the wind direction. The alternate shedding of vortices is regular. As a result, a so-called Karman vortex street is formed. When the frequency of the shedding of vortices is approximately equal to one of the frequencies of free vibrations of a conductor, a 'lock-in' phenomenon occurs. During this frequency synchronisation, the conductor is in the resonance state. Aeolian vibrations occur on single conductors and conductors in a bundle. Although these vibrations are hardly noticeable due to low amplitude values (lower than the conductor diameter), they are very important, since they can lead to fatigue destruction of a conductor in points of high stress concentrations.

Galloping. This phenomenon was observed for the first time on ice-covered power lines subject to strong wind. Galloping is an aeroelastic self-excitation phenomenon characterised by low frequencies and high amplitudes, and it refers to single conductors and conductors in a bundle, with one or two loops of standing and running waves, or their combination in a conductor span. Standing waves may have one or more loops (up to 10) over the span length. However, a small number of loops is predominant. In most cases, galloping is caused by sustained wind of an average and high speed ($V > 15$ m/s), blowing on an asymmetrically loaded (e.g. with ice or wet snow) conductor. High amplitudes are observed in the vertical plane, whereas the frequencies depend on the type of a conductor and vibrations (EPRI Research project 792, 2005). Galloping is a typical instability caused by the coupling of aerodynamic forces which affect the conductor with its vibrations. Conductor vibrations change he wind angle of attack on a periodic basis. The change of the angle of attack results in a change of aerodynamic forces affecting the conductor, which consequently changes the conductor response. The first, simplified criterion (if a single degree-of-freedom system is applied) pertaining to the instability connected with galloping was presented by Den Hartog. A precondition for galloping (on the basis of the quasi-steady theory) is the presence of negative aeroelastic damping in the system. A conductor of a circular section cannot gallop due to its geometrical symmetry ($dC_L / d\alpha = 0$), unless this section is changed. Icing of a conductor changes its cross-section, thus it leads to its aerodynamic instability (Farzaneh, 2008). Research works carried out by Hartog indicate that the aerodynamic instability is the main reason for the galloping phenomenon. His research was conducted with an assumption that the vertical motion of a conductor is predominant, and the effect of torsional and horizontal motions can be ignored. Further research proved that the torsional motion is an integral part of the galloping phenomenon. The effect of a coupled torsional-translational motion plays a crucial role in most cases of progressing galloping (Luongo, 2009).

Wake induced vibrations

Unlike aeolian vibrations or galloping, wake induced vibrations can occur only on conductor bundles and only when one conductor lies within the wake of another conductor. Wake induced vibrations are caused by sustained wind of an average and high speed ($V > 10$ m/s). As opposed to galloping, these vibrations may occur all year round. An amplitude of these vibrations is not that high as for galloping. However, they can lead to destruction of conductors, clamps or dampers. They are not as common as aeolian vibrations.

3. Methods of vibration control

Popular methods of reducing vibrations of power line conductors can be divided as follows: aerodynamic-structural methods (application of dual-conductors – twisted pair, oval cross-section conductors, self damping conductors) and mechanical methods (mechanical dampers mounted on conductors or conductor bundles). Commonly used equipment for damping overhead power line conductor vibrations includes: dampers of type Stockbridge, spiral dampers, torsional dampers, spacers with damping properties (for conductor bundles). Selected, effective mechanical dampers are described below.

Stockbridge dampers are most frequently used dampers on overhead power lines (Fig. 1a). A classic Stockbridge damper consists of two 'inertial masses' (metal weights) clamped at the ends of a specially designed short steel wire strand (messenger) attached with a clamp to the damped conductor. The energy of vibrations is dissipated through friction caused by slippage between the messanger wires. When the damper is positioned on a vibrating conductor, the vertical motion of the weights forces the steel conductor to bend, causing friction between the wires which dissipates the energy. The size and shape of the weights and damper geometrics influence the quantity of energy dissipated for specific vibration frequencies. An improved version of the classic damper (an asymmetrical Stockbridge damper) features two different weights in the shape of a bell, located asymmetrically at the ends of a steel galvanised messenger of possibly the best energy dissipation properties. Such a design of the damper doubles the number of resonance peaks from two obtained with the classic version of the Stockbridge damper to four in the improved version. Modern Stockbridge dampers are intended for effective energy transfer and dissipation for the whole spectrum of frequencies within aeolian vibrations. To ensure effective damping, the first damper should be located next to the attachment (suspension), inside the shortest loop which is formed at the highest speed of wind (7 m/s) (Technical Report IEEE, 2015).

The Spiral Damper (impact type damper) has been applied on small diameter conductors (≤ 19 mm) for over 30 years. It is made of rugged non-metal material in the form of spiral of length 1.2 – 1.5 m, with an internal diameter exceeding the conductor diameter. A spiral at the one end adheres tightly to the conductor (the supporting part). During aeolian vibrations, the damping part of this spiral impacts the conductor and causes formation of impulses which disrupt conductor vibrations (Technical Report IEEE, 2015). Another type of spiral damper is the **Air Flow Spoiler**. It can be used on conductors in order to balance aerodynamic lift forces which cause galloping. Usually, spoilers cover approx. 25 % of the span length and are used in two groups (Conductor Galloping Basics, 2016).

The **Detuning Pendulum** is used for single cables and cables in a bundle. A typical design of the damper is a weight attached to a cable or cable bundle. The length of the arm and weight depend mainly on the cable diameter and span length. Arm length and weight required to overcome moment of ice and wind load, thus minimizing or eliminating galloping. This damper separates frequencies of vertical vibrations from frequencies of torsional vibrations. In most cases, 3 - 4 dampers are installed along the span, using braids in order to decrease local cable tensions (EPRI Research project 792, 2005).

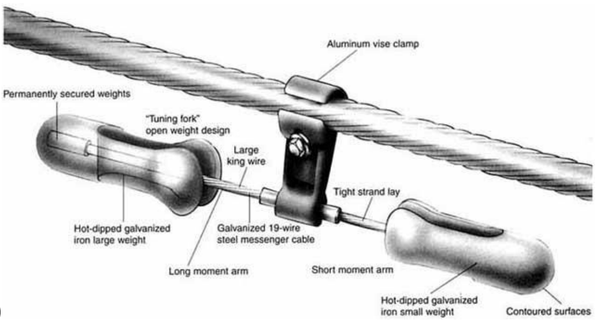
The **Torsional Damper and De-tuner** is a modern damping device. It combines properties of a torsional damper and detuner. This damper uses a torsional motion of a conductor during galloping to damper vibrations, and improves its effectiveness by separating frequencies of vertical vibrations from frequencies of torsional vibrations, as in pendulum dampers. This damper increases the value of a critical speed of wind, above which galloping occurs, and reduces its amplitudes. In most cases, 2 - 3 dampers are installed along the span (Vinogradov, 2012).

For controlling galloping for single conductors (shorter span), and for controlling aeolian vibrations (in conductors of small diameters and spans) can be used **AR Twister dampers**. Three types of AR Twisters are manufactured: Piston, Kanister and Slider (Fig. 1b) (AR Products LLC, 2015). Twisting is the main technique for galloping control in all these dampers. All AR Twister dampers reduce or eliminate galloping of a conductor by making the conductor rotate and – as a consequence – decrease the aerodynamic lift. The AR Twister is an inertial device made of aluminium (due to its weight and durability). Damping required to control aeolian vibrations is achieved by rubbing metal with metal, as a result of slight motions between the device body and its clamp. These devices are rigidly fixed to the conductor with standard vertical clamps (over the conductor) or clamps which are angled at 45 ° to 60 °. Such an arrangement of dampers causes an initial torsion of the conductor under gravity forces. In the event of galloping, inertial forces affect the device making the conductor twist again, in the opposite direction to its initial position. When galloping, torsional oscillations increase, ice sediment is distributed over the greater surface of the conductor and the profile becomes smooth and less eccentric. At the same time, the aerodynamic lift force is reduced and the level of vibrations decrease (AR Products LLC, 2015).

A **damping spacer** combines the function of maintaining distance between conductors (preventing their damage caused by impacts) with the function of vibration damping. Depending on the arrangement of conductors in a bundle, different types of spacers are available. Rigid and spring spacers are usually used for controlling galloping. Early versions of rigid spacers comprised ceramic insulators connected with an aluminium tube and attached to conductors with standard suspension. At present, light polymer insulators are applied. A modern spacer for a conductor bundle consists of a rigid aluminium frame (body) and several jibs (clamps), the number of which is determined by the number of conductors in the bundle. The jibs are attached to the frame with special resilient joints. In addition to the basic function of maintaining spacing between the conductors, this damper provides vibration damping by means of damping pads in body-clamp connections, and is used to limit bending stresses and – consequently – to reduce deformations in bundle conductors.

AR Spacer / Twister can be mounted on a single conductor or conductor bundles in a vertical or horizontal position. This device is designed to reduce the level of vibrations in low unit weight conductors. AR Spacer/Twister combines the advantages of the twisting action of the AR Clamp with the features of the polymer insulators. AT Twister eliminates galloping by making the conductor twist, thus resulting in a decrease of the aerodynamic lift force (AR Products LLC, 2015).

AR Mood 2 Spacer Damper is mounted horizontally or vertically on conductor bundles in order to control galloping. This device consists of a steel spring rim and aluminium clamps. Articulated clamps rotate on the rim, allowing the conductor to rotate and twist, while maintaining distance between the individual conductors. The effective performance of this spacer/damper is ensured by large rotation angles which effectively change the wind angle of attack during galloping (AR Products LLC, 2015).



a)


b)

Fig. 1: a) Stockbridge damper (Hubbell Power Systems, 2016) and b) AR Twister dampers (AR Products LLC, 2015)

4. Conclusions

Vibrations of overhead power line conductors caused by wind may lead to their destruction. Therefore, reducing the level of such vibrations is important due safety of the entire structure. Common methods of minimization of conductor vibrations are passive: proper shaping of the external surface of a conductor, a proper design of the conductor (self-damping) and use of special damping devices, depending on the type of excitations.

At present, there is no way to completely reduce vibrations during galloping, for which amplitudes may reach high values. According to the research literature, Air Flow Spoilers and torsional dampers are most effective in minimizing conductor galloping, whereas Stockbridge dampers are still the most efficient devices for aeolian vibrations and spiral dampers are excellent for very small diameter of conductors.

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