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A Review Paper on Analysis, Methods and Applications of Stock Bridge Dampers in Transmission Lines

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ABSTRACT

This research delves into the effectiveness of asymmetric Stockbridge dampers in mitigating wind-induced vibrations in power transmission lines, particularly focusing on an innovative damper design that generates more than four resonance frequencies. By examining wind load responses and vortex-induced vibrations (VIV) in long-span cable-supported structures, the study underscores the crucial role of Stockbridge dampers in controlling dynamic stress and enhancing transmission line durability. The research integrates theoretical findings with experimental verification, deriving expressions for damper response and dynamic stresses. Utilizing a machine with five profiles and employing Genetic Algorithms to estimate key material properties, the study conducts a sensitivity analysis of design parameters, providing comprehensive design guidelines. The findings confirm the theoretical models, highlighting the dampers' significance in maintaining the structural integrity and operational efficiency of power transmission systems.

Keywords: asymmetric Stockbridge dampers, vortex induced vibrations (VIV), dynamic stress, damper response, genetic algorithms

1. Introduction

Stockbridge dampers are essential components used to protect conductors in power transmission lines from aeolian vibrations, which can lead to significant mechanical fatigue and eventual failure. The effectiveness of these dampers hinges on achieving optimum impedance, which varies between suspension and dead-end spans due to differing dynamic interactions between the damper and the tension system. This research focuses on the development and optimization of asymmetric Stockbridge dampers designed to mitigate wind-induced vibrations in transmission lines by producing multiple resonance frequencies, thereby enhancing their efficiency. A comprehensive study is conducted on the wind-induced response of long-span cross-rope suspension transmission lines, examining key factors such as structural performance, wind load response, and vortex-induced vibrations.

In addition to theoretical analysis, this study introduces innovative design improvements, including a low-mass clamp for better damper performance, and investigates the dynamics of Stockbridge dampers using both linear and nonlinear models. By comparing experimental and numerical results, the research validates the dynamic behavior of these dampers and explores their design sensitivity to resonant frequencies, emphasizing spectral energy dissipation efficiency. An analytical approach employing a double-beam concept is utilized to derive exact solutions for natural frequencies and mode shapes, providing a robust framework for optimizing damper design and enhancing the vibration mitigation capabilities of power transmission lines.

2. Analysis of Stockbridge Dampers

Stockbridge dampers are vital components used to protect conductors in power transmission lines from aeolian vibrations, which can cause mechanical fatigue and eventual failure. The effectiveness of these dampers hinges on optimal impedance tuning, which varies between suspension and dead-end spans due to their unique dynamic interactions. This study explores the enhanced performance of Stockbridge dampers modified with additional masses, enabling them to produce six resonance frequencies. These modifications significantly improve the damper's effectiveness, thereby extending the lifespan of transmission lines. A critical aspect of this research is the use of wave impedance analysis to model the interaction between the conductor and the vibration damper system, which comprises a massless spring and a rigid mass damper.

In-depth investigations into the dynamics of Stockbridge dampers reveal both translational and rotational vibration responses, analyzing their linear and nonlinear behaviors under excitation frequencies ranging from 5-17 Hz. The performance of the dampers is validated through comparisons with impedance curves obtained from conventional testing, ensuring the accuracy of the theoretical models. Additionally, Genetic Algorithms are employed to estimate critical material properties such as the loss factor and Young's modulus, providing a comprehensive understanding of the damper's material characteristics. The study finds that the inclusion of additional masses not only increases the number of resonance frequencies but also enhances the energy dissipation efficiency, improving the overall performance of the dampers. Moreover, a low mass clamp design is introduced, which significantly boosts damper efficiency at high frequencies.

Fig. 1 – Stock bridge dampers

A comprehensive sensitivity analysis is conducted on key design parameters, such as messenger wire length, counterweight inertia, and gyration radius, to determine their influence on resonant frequencies and energy dissipation efficiency. This analysis is validated through case studies on eigenvalues, offering robust guidelines for optimizing damper design. The double-beam concept is employed to model the vibration transmission line, with experimental validation confirming the accuracy of the analytical models. These findings underscore the importance of precise design adjustments to enhance the damper's performance. Despite these advances, the study notes that the influence of damper location on system natural frequencies remains inconclusive, highlighting a potential area for further research.

Overall, this research underscores the critical role of Stockbridge dampers in controlling aeolian and wind-induced vibrations in overhead transmission lines. By optimizing damper design through advanced modelling techniques and sensitivity analyses, the study provides valuable insights into improving the durability and efficiency of power transmission systems. The integration of additional masses and innovative clamp designs showcases the potential for significant advancements in damper technology. Future research should continue to explore the dynamic interactions and optimal placement of dampers to fully leverage their vibration mitigation capabilities, ensuring the continued reliability and safety of power transmission infrastructure.

2.1. Experimental Work

The experimental work in this study focused on validating the energy balance method for analysing conductor vibrations in power transmission lines. Bending strains were computed at critical points, such as dead-end clamps and insulator couplings, to assess the effectiveness of the vibration mitigation strategies. A significant part of the investigation involved using an electro-dynamic shaker to apply input forces during tests on an asymmetric Stockbridge damper, which had been modified with additional masses to produce multiple resonance frequencies. These experimental tests were crucial for understanding the damper's dynamic response to wind-induced vibrations on long-span cross-rope suspension transmission lines, especially in challenging environments like mountainous areas.

Extensive wind load analysis was conducted on conductors and suspension cables, with measurements taken to validate theoretical predictions using the Wave Separation Method. The characteristics of the damper were tested on a specific span following detailed procedures, and the findings consistently verified theoretical predictions regarding the Stockbridge damper's response. To ensure comprehensive validation, stresses on the cable were both theoretically determined and experimentally measured, confirming the reliability of the theoretical models. Fatigue tests were performed on the damper to evaluate its durability and performance under prolonged operational conditions. Additionally, the dynamic behaviour of the Stockbridge dampers was analysed using a cam machine with five profiles, which helped in estimating the loss factor and Young's modulus through a combination of experimental and numerical results.

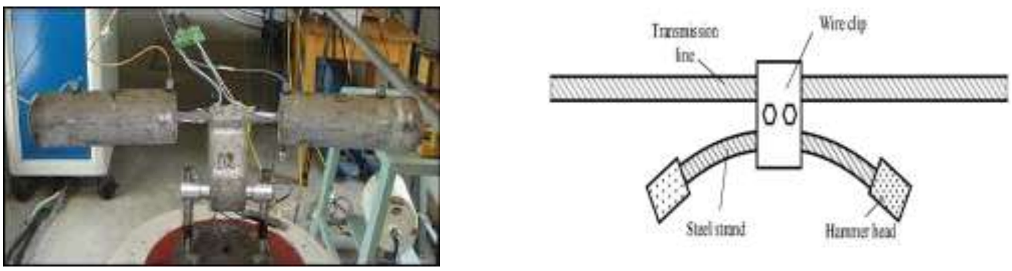

Fig. 2 – Experimental Setup of Stock Bridge dampers

Numerical models were developed using the Finite Element Method (FEM) and compared against experimental data obtained from the cam machine experiments. This comparison allowed for the adjustment of physical parameters to enhance the accuracy of the models. Sensitivity analysis on various design parameters, such as messenger wire length and counterweight inertia, was conducted to determine their impact on resonant frequencies and energy dissipation efficiency. These analyses were further validated through case studies on eigenvalues with varied design parameters, leading to the formulation of simplified sensitivity equations for each eigenvalue. Experiments involved exciting the conductor at frequencies ranging from 10-45 Hz using a dynamic signal analyser for data acquisition and processing. Conductors were loaded in tension using a hydraulic ram cylinder at specific tensions of 27.84 KN and 34.8 KN, providing a robust framework for understanding and optimizing the performance of Stockbridge dampers in real-world conditions.

3.Methods Used

The methods employed in this study integrate advanced computational modelling, detailed experimental testing, and rigorous theoretical analysis to optimize the performance of Stockbridge dampers near dead-end towers. A key component of the approach was the development of a computational model to determine the optimum damper impedance, facilitated by introducing a dimensionless impedance function for analysing the tension system. Experimental tests were conducted with asymmetric Stockbridge dampers, where additional masses were used to investigate and fine-tune the resonance frequencies. An electro-dynamic shaker and amplifier provided precise force input, simulating wind-induced vibrations. Wave impedance analysis was utilized to model the interaction between the conductor and the damper, ensuring a comprehensive understanding of the damping mechanisms. Measurements of power dissipation at constant antinode velocity were conducted to validate the theoretical models, focusing on the energy transfer and dissipation efficiency of the dampers.

Theoretical analysis of the Stockbridge dampers involved determining the dynamic stresses on stranded cables and verifying these predictions through experimental results. Genetic Algorithms were employed for the estimation of crucial parameters, such as the loss factor and Young's modulus, enhancing the accuracy of the models. Both linear and nonlinear mathematical models were used to adjust data and refine the experimental results. Design sensitivity analysis, using partial derivatives, examined the eigenvalues concerning various design parameters, further supported by partial differential equations to investigate these relationships. The study calculated eigenvalues for a half Stockbridge damper under undamped conditions and applied Hamilton's principle for the analytical modelling of vibration behaviours. These theoretical and computational insights were then experimentally validated using a dynamic signal analyser and an electromagnetic shaker, ensuring the reliability and robustness of the findings.

3.1. Applications

The application of Stockbridge dampers is critical for the protection of conductors from aeolian vibrations in overhead transmission lines, significantly extending their lifespan by suppressing wind-induced vibrations. By enhancing the performance of these dampers to produce six resonance frequencies, the efficiency of vibration mitigation is greatly improved, ensuring the stability and durability of the transmission lines. This is particularly important in structurally assessing long-span Cross-Rope Suspension (CRS) systems in challenging environments like mountainous areas, where wind-induced vibrations are more pronounced. The use of Stockbridge dampers is also essential for damping high-frequency vibrations in optical ground wires, by protecting the integrity of both power transmission and communication systems.

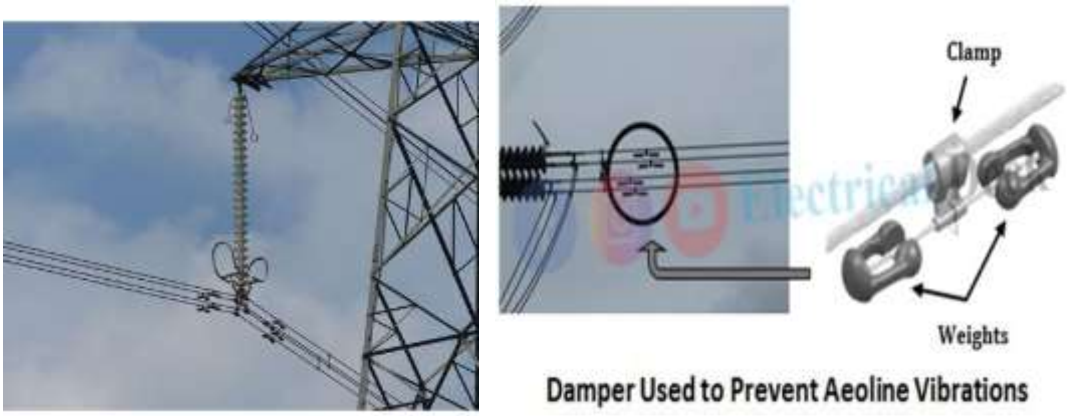

Fig. 3 – Stock bridge dampers used in transmission lines

Advanced computational techniques, such as Genetic Algorithms, are employed to estimate key material properties like the loss factor and Young's modulus, which are crucial for adjusting parameters in numerical models developed through the finite-element method. This allows for precise control of aeolian vibrations in transmission lines, optimizing the performance of Stockbridge damper systems. Design sensitivity analysis is used to determine resonant frequencies and investigate the effects of damper characteristics and locations on system frequencies. These analytical results are validated experimentally, ensuring robust vibration analysis and mitigation strategies for overhead transmission lines. By effectively reducing vibrations in conductor spans, Stockbridge dampers play a vital role in maintaining the reliability and efficiency of power transmission infrastructure.

3.2. Advantages of Stockbridge dampers

- Efficiently protect conductors from aeolian vibrations.
- Stockbridge dampers have multiple resonance frequencies for efficient vibration suppression.
- Enhanced performance leads to longer lifespan of transmission lines.
- Control wind-induced vibration effectively.
- Widely used in power transmission lines for vibration control.

- Reduce high frequency vibrations effectively.
- Easy installation and inspection.
- Dissipate real power through force and moment components.
- Control aeolian vibrations in transmission lines.
- Improve transmission line performance.

3.3. Limitations

The utilization of specially designed Stockbridge dampers, particularly in dead-end spans, is often impeded by economic constraints, as the associated installation and maintenance costs may outweigh the potential benefits. Moreover, practical challenges hinder meeting the dynamic requirements of these dampers, limiting their effectiveness in mitigating vibrations. Despite recognized advantages, such as the ability to produce multiple resonance frequencies, limited research exists on optimizing asymmetric dampers, while festoon dampers lack established design rules, hampering their implementation. Vulnerabilities in long-span Cross-Rope Suspension (CRS) systems to larger vortex-induced vibration (VIV) amplitudes further underscore the need for more effective damping strategies. Additionally, conventional dampers exhibit shortcomings in damping high-frequency vibrations, and uncertainties persist regarding the evaluation of damping coefficients, hindering accurate performance assessments. Dynamic reactance issues due to lose cable attachments, coupled with challenges in modelling hysteretic damping and restricted frequency ranges for effective study, present further limitations in the optimization of Stockbridge dampers.

4. Conclusions

In conclusion, the study highlights the critical importance of optimizing Stockbridge dampers, particularly in dead-end spans, where the dynamic interaction with the tension system necessitates tailored impedance tuning. It emphasizes that the efficiency of standard dampers can be significantly enhanced by proper placement, ensuring optimal damping performance throughout the transmission line. The research underscores the potential consequences of insufficient damping in dead-end spans, which may lead to fatigue failure and compromise the overall integrity of the system. By introducing modifications to conventional dampers, such as enhancing them to produce six resonance frequencies or employing asymmetric designs to generate more resonance frequencies, the study demonstrates tangible improvements in the transmission line's lifespan and structural resilience.

Moreover, the findings shed light on the intricate dynamics of wind and ice-induced vibrations in long-span Cross-Rope Suspension (CRS) systems, showcasing the effectiveness of dampers in reducing amplitudes and ensuring stable operation. The development of lightweight damper clamp designs emerges as a significant breakthrough, substantially enhancing damping performance without adding undue strain to transmission structures. Additionally, the validation of Stockbridge dampers as two-degree-of-freedom systems underscores their efficacy in absorbing oscillations through efficient energy dissipation. The alignment between theoretical stress calculations and experimental findings further reinforces the reliability of these dampers in real-world conditions. However, the study acknowledges the complexities involved in nonlinear parameters and the inconclusive role of damper location on system natural frequencies, suggesting avenues for future research to refine and optimize Stockbridge damper designs for even greater effectiveness in mitigating transmission line vibrations.

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