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Cable Vibration Considering Interlayer Coulomb Friction

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A new modeling approach for internally damped, vibrating cables is proposed. Instead of the addition of a damping term in the governing cable equation of motion, it is demonstrated that the variation of cable flexural rigidity with helical wire slip causes frictional energy dissipation and damping of the cable oscillations. Model results compare favorably with tests performed on a Stockbridge damper cable.

INTRODUCTION

The cable is a complex structure consisting of multiple layers of helically served wires, often of dissimilar materials. The helical structure renders flexibility to the cable that varies with the curvature of the cable axis. The mechanism for this variation is wire slip as bending-induced tension gradients exceed interlayer frictional forces. A vibrating cable is characterized by flexural rigidity that varies along the cable axis and with time. The stick-slip mechanism is modeled by assuming that frictional forces can be computed as Coulomb forces, independent of frequency. Thus, a static analysis of wire slip versus curvature suffices.

Varying flexural rigidity (*EI*) introduces strong nonlinearity in the governing equation of motion of the cable as *EI* changes in discontinuous jumps with change of curvature. An analytical solution of the 4th-order partial differential equation for a cable exhibiting wire slip likely is impractical, and so a numerical solution has been applied.

Other potential nonlinearities such as nonlinear material behavior and large deflections are assumed to be negligible to simplify the equation of motion. The cable can be subjected to a constant tension that produces radial pressures between layers, or radial pressure can be produced without tension by manufacturing the cable with helical wires preformed to clinch subjacent layers. The latter case describes the study of a self-damped cable performed in this paper.

The motion of the cable is simulated by applying variational theory, and a 5th-order polynomial of a Hermite interpolation function is introduced to simulate the configurations of the cable. The cable system simulation also incorporates a flexural rigidity-curvature relationship, instead of an external damping term to simulate the effect of internal friction due to the rubbing of the strands in the cable. The cable equations are solved using an implicit Newmark time integration scheme with linear acceleration written in an incremental form. The least square curve fitting technique is used to remedy nonsmooth solutions.

The numerical results show that variation of *EI* produces damping of vibration without use of an explicit damping term in the cable equation. Numerical results show general agreement with experimental data reported in the literature.

Figs. 1 and 2 depict the model of a Stockbridge self-damped cable examined in this paper. By introducing sufficient wire preform, interlayer radial pressure is produced. This pressure causes friction at the layer interfaces that dissipate energy as the cable vibrates, and individual wires alternatively slip and stick along their helical paths.

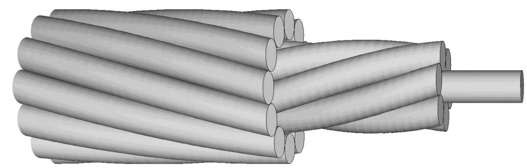

Fig. 1 Self-damped cable

Background

Gutzer, Seemann and Hagedorn (1995) developed a MASING model for self-damped stranded steel cables. Their approach to modeling such cables is to treat the cable as a collection of discrete and continuous systems of bonded wire layers. Each of the layers consists of one or more parallel JENKIN or PRANDTL elements. The stick-slip behavior between the structural parts is simulated as a special case of static hysteresis. A slowly varying amplitude method and a phase method were used in the simulation to identify the damping parameters of physical systems.

Sauter and Hagedorn (2002) and Sauter (2003) performed experiments with a self-damped cable supported at one end and free at the opposite end. By measuring cable response to a cycli-

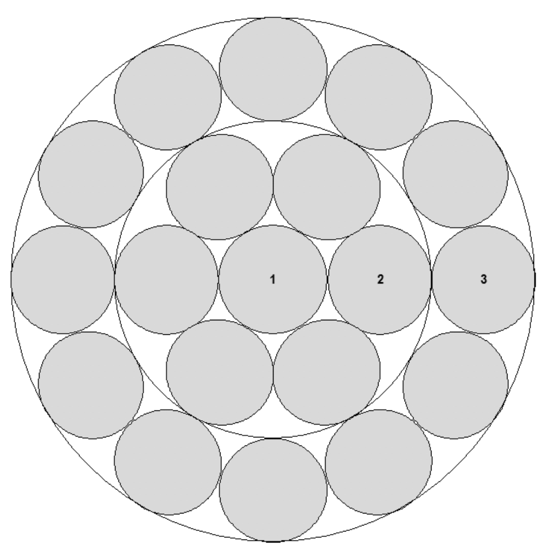

Fig. 2 Self-damped cable cross-section

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