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FINITE ELEMENT MODELING OF HIGH-VOLTAGE CABLE CONDUCTOR STRUCTURE UNDER ALTERNATING BENDING LOADS

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ABSTRACT

The continuing global transition towards electric vehicles brings increased attention to the reliability and durability of high-voltage (HV) cables, which are key components of electric powertrains. HV cables are frequently subjected to cyclic loadings induced by road vibrations, whose effects on internal cable degradation remain poorly understood. The internal structure of HV cables, composed of hundreds of wires wound into subgroups called bunches, leads to intricate internal kinematics which are difficult to analyze due to the large number of interwire contacts involved. Consequently, very few studies have investigated internal wire solicitations that may initiate damage mechanisms like fretting fatigue or wear. This knowledge gap hinders advancements in cable design optimization and performance analysis.

This study introduces a Finite Element (FE) model aiming to describe the internal kinematics of HV cable conductor structure subjected to alternating bending loads. The analysis focuses on a 100mm long cable segment, composed of 364 wires grouped in seven bunches, protected by an external polymer jacket. The bending load cycle is induced considering a cantilever configuration with minimum curvature radius reaching 10 times the cable diameter. To replicate the complex HV cable stranded structure geometry, the modelling approach incorporates a previously developed method capable of simulating wire bunch compaction during manufacturing, resulting in highly realistic HV cable conductor representations. The FE model accounts for all individual wires using an efficient beam element discretization, and shell elements simulate the polymer insulation jacket. Wire-to-wire and wire-to-jacket contact interactions are modeled using a beam-to-beam and a beam-to-surface contact algorithm, respectively.

The FE analysis results were compared to experimental load-deflection curves, showing a good correlation between the simulation results and the observed cable cyclic hysteresis. The analysis of internal wire solicitations indicates that inter-bunch contacts experience greater contact forces and undergo a fivefold increase in slip movements in comparison to intra-bunch interactions. This implies that inter-bunch areas are more susceptible to fretting and wear-related damage. Moreover, results analysis reveals a strong influence of parameters such as interwire friction and initial polymer jacket pressure, indicating that these factors deserve further investigation. The proposed model therefore provides interesting insights on the HV cable internal kinematics that could support the cable selection and optimize routing strategies.