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Failure analysis for vibration-based energy harvester utilized in high-speed railroad vehicle

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ABSTRACT

This study aims to analyze the failure mechanism and improve the structural design of a vibration-based energy harvester (VEH), which intends to replace or extend the service life of batteries for condition monitoring systems of high-risk structures such as railroad vehicles and wind turbines. The observation of a fractured VEH under service condition of high-speed railway vehicle reveals several cracks originating on the surface of the VEH. A vibration test in the laboratory, conducted by using an electromagnetic exciter, identifies the resonant frequency, displacement-frequency, and acceleration-frequency plots of the VEH. A comparison of the surface fractured during vibration testing with that under service condition indicates that the major failure mechanism is static brittle fracture. The failure critical location and stress states are identified through frequency response analysis. Several measures are recommended to prevent the failure of VEHs, including selecting materials and redesigning the moving component of VEH.

1. Introduction

Vibration-based energy harvesters (VEHs) utilize the vibration generated from various structures [1,2]; they are designed so that their natural frequencies are within the frequency range of dynamic loads that originate from structures and/or components to enhance the efficiency of power production [3]. Such VEHs intend to replace the batteries or extend their service life for condition monitoring systems of high-risk structures such as railway vehicles and wind turbines [4]. Condition monitoring systems should measure and transmit the safety-relevant data of high-risk structures during their service life without any interruption; hence, VEHs should have sufficient reliability and durability during the service life time.

The VEH is normally designed to be attached to a vibration-generating structure by a shaft; the vibration is transmitted to the main body through a leaf-spring-shaped moving component that connects the shaft and the main body. Fig. 1 shows the structural design of the electromagnetic VEH studied in this paper. The resonance between the transmitted vibration and the VEH makes the relative displacement between the neodymium magnets and the coils maximum; this displacement is governed by the structural response of moving component. Therefore, the reliability and durability of a VEH is usually determined by the structural integrity of the moving component.

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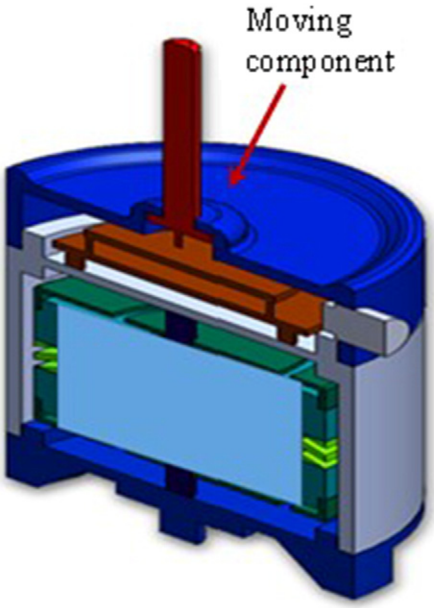

Fig. 1. Design of vibration-based energy harvester.

The prototype of VEH described above was installed and tested on a high-speed train as shown in Fig. 2 and failure of the moving component was observed. Fig. 3 exhibits the failed moving component (leaf spring) in the VEH under service condition. Such a failure may occasionally occur in various mechanical structures and/or components; hence, many studies have investigated failure mechanisms and failure modes [5–7]. However, these failure mechanisms and failure modes are still not clear because of the complexity of external loads, structural geometry, machining process and mechanical responses of the failed structure or components.

This study aims to investigate the failure mechanism and improve the structural design of the VEH. For this purpose, we first observed the surface of a broken spring of VEH under service condition using a scanning electron microscope (SEM). To identify the performance and structural integrity of the VEH, particularly its moving component, a vibration test was performed under sinusoidal acceleration environment. Then, frequency response analysis was performed to identify the failure critical location (FCL) and system responses such as stress distribution. Finally, we recommended several measures to prevent the failure of the moving component in VEHs.

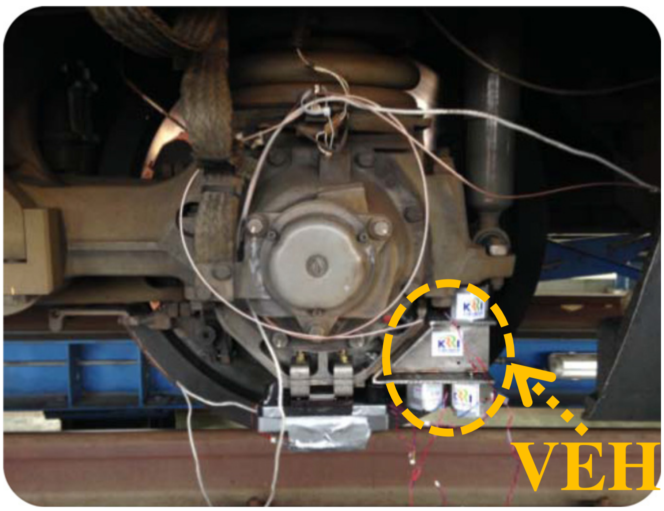

Fig. 2. Installed VEH on axle of high speed train.