Effect of Phase angle of Acceleration on Fatigue life in Frequency Domain of Vibration-Based Energy Harvester for Railway vehicle

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ABSTRACT

This study aims to perform fatigue life prediction of vibration-based energy harvester (VEH) considering resonance characteristics. First, we investigated the vibration environment of a structure on which an energy harvester may be installed and determined the level and frequency range of the power spectral density (PSD) exerted on the energy harvester. On the one hand, this research considered random vibration load, because VEH was operated by resonance phenomena. So, to consider random load, life prediction was performed by durability test machine and system. And in order to consider dynamic effect by natural frequency, vibration fatigue analysis was performed in frequency domain. Also, we were performed durability test and vibration fatigue under random load, which is composed of the PSD. As results, accuracy of life prediction procedure for VEH by vibration fatigue analysis was verified.

1. INTRODUCTION

In recent years, the continued drop in power requirement of electronic sensors (Moss, 2012) has led to remarkable scientific and engineering interest in energy harvesting technologies (Priya, 2009). There are various energy sources for energy harvester such as electromagnetic, photovoltaic, vibration, thermal, water turbines, and wind power (Andosca, 2012). Among them, mechanical vibration is one of the most promising energy sources that could be taken advantage of for many applications in their relevant environments.

Vibration-based energy harvesters (VEHs) (Roundy, 2005) utilize the vibration generated from various structures or components and specifically, are designed that their natural frequencies are within the frequency range of dynamic loads that originate from the structures and/or components and consequently augment the displacement of moving parts in VEH, in order to enhance the power production efficiency(Goldschmidtboeing, 2008). Such VEHs intend to replace or extend service life of batteries for condition monitoring system for high-risk structures such as railway vehicle and wind turbine, in which it is hard to supply the electrical power for data measurement and transmission(Roundy, 2003). The condition monitoring system should measure and transfer the safety-related data of high-risk structures during their service life without intermission. Hence, VEHs should have the sufficient durability, to monitor the safety or structural integrity of high-risk structures. Therefore, it is more important than ever to evaluate the durability of VEH in order to make VEHs reliable for monitoring the condition of high-risk structures.

In this study, fatigue life of a vibration-based energy harvester in the frequency domain was verified. Based on this, the fatigue life according to the phase angle was predicted.

2. ANALYSIS PROCEDURE

To identify the response of VEH to external loads in the frequency domain, MSC Patran/Nastran (2006) was used to conduct frequency response analysis. The finite element model was constructed using solid (CTETRA) and shell (CTRIA3) elements; the number of elements and nodes were 49064 and 14507, respectively. And, multi point constraints (MPC) were used between the solid and shell elements to prevent the hinge connections that could result from a mismatch in degrees of freedom. Additionally, the directions of x, z, xr, yr and zr were fixed at the lower end of the main shaft. For the loading condition, accelerations of 0.5g, 1g, 2g, and 3g were applied at the lower end of the main shaft. The range of frequency response analysis was set at fn ± 10 Hz with the increments of 0.2 Hz. Fig. 1 shows the finite element (FE) model of the VEH used in the frequency response analysis. The materials used in construction of the VEH were SKD61, SM45C, ABS and neodymium magnet; data on their properties were obtained from an open source.The loading condition(Fig. 2) used PSD loading history in the frequency domain. Also, fatigue analysis should consider material fatigue character conditions. For this, *S-N* curve was obtained through the standard fatigue test.

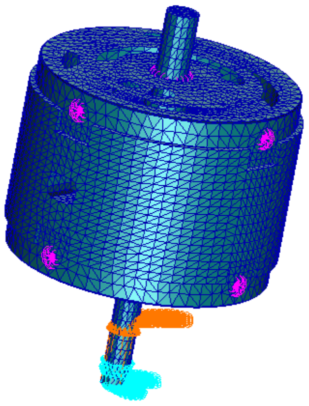

Figure 1. FE model for basic VEH.

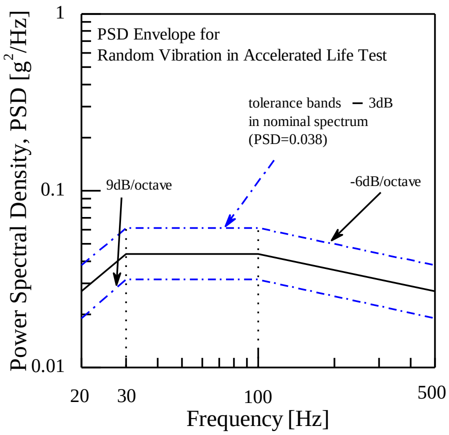

Figure 2. Power spectrum density condition.

3. VIBRATION FATIGUE ANALYSIS

3.1. Frequency Response of VEH

Because the VEHs maximize their power generation through resonance of the excitation and natural frequencies, the stress or displacement response of the VEH in the frequency domain must be analyzed to ascertain its structural integrity. The transfer function of a structure is defined as the structural response per unit input at each frequency of interest. The transfer function is completely independent of the input loading and is a fundamental characteristic of the system or model (McGreevy, 1999).

Among the results from the frequency response analysis, Fig. 3 shows the stress (von-Mises stress) distribution of the moving component in the VEH, excited at its eigenfrequency. The maximum stress occurred at node #63634.

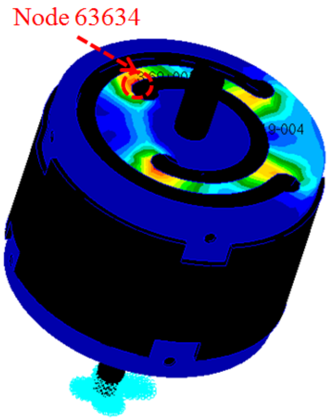

Figure 3. Max. stress position of VEH for frequency response analysis.

3.2. Fatigue Life of VEH

In order to predict the fatigue life in frequency domain, vibration fatigue analysis was performed using frequency analysis results, load history in frequency domain and *S-N* curve for the material. This is the result of vibration fatigue analysis applied to PSD load history. As shown in the fig.4, the failure location was the same in the durability test and the vibration fatigue analysis, and fatigue life was evaluated at the maximum critical location.

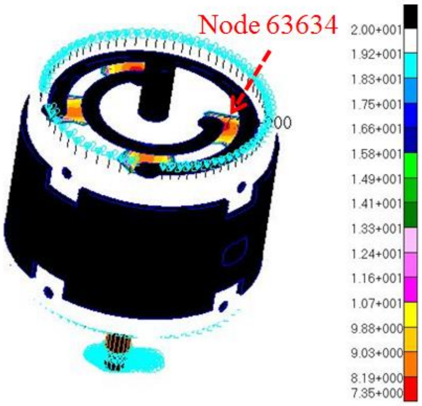

Figure 4. Contours for result of vibration fatigue analysis.

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By analyzing the minimum life domain, fatigue cracks will occur in the spring. Damage rate and life in maximum critical location(node 63634) was estimated $4.47x10^{-8}$ damage/sec and life is $2.24x10^{7}$, respectively. This result can be converted to 6218 block, where 1 block defines the PSD as 3600 seconds. Also, the load history defined by PSD is the same condition as moving from Seoul to Busan by KTX.Currently, KTX has three round trip from Seoul to Busan on a day and maintenance period of 100 days on a year. Considering this, life of VEH is estimated about 5 years. These results was predicted by vibration fatigue analysis.

4. CONCLUSION

In this paper, the fatigue life is predicted according to the phase angle of the vibration-based energy harvester in the frequency domain.

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