Development of Tuned Dual-Mass Electric Power Generator for Energy Harvesting of Bridge Vibration

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Summary

A high quality bridge vibration energy harvester has been proposed in this paper using a tuned dual-mass damper system, named hereafter Tuned Mass Generator (TMG). To harvest and make use of the unused reserve of energy the aforementioned damper system absorbs, a new type of linear electromagnetic transducer has also been applied. The benefits of using dual-mass systems over single-mass systems for power generation have been clarified according to the theory of vibrations. TMG parameters have been determined considering multi-domain parameters, and TMG has been tuned using a newly proposed parameter design method. Experimental results obtained from a trial bridge have verified that for effective energy harvesting, it is essential that TMG has robustness against uncertainties in bridge vibrations, and the proposed TMG has demonstrated this feature.

Keywords: bridge vibration; energy harvesting; tuned mass damper; electric power generator.

1. Introduction

Vibration-based energy harvesting has been studied in various fields, and research is emerging in the field of civil engineering also. One area of growing interest is the potential for harvested vibration energy to supply electric power to wireless sensing devices, or other intelligent systems for the health monitoring of bridges [1]. Of the many new developments, tuned mass damper systems have been found to satisfactorily control vibration when an ideal dynamic balance is achieved between mass, springs and dampers. However, the performance of tuned mass damper systems is highly sensitive, as they have a narrow target frequency range and have low robustness against changes in vibration frequency, and so various parameter design methods have been proposed [2]. One difficulty of parameter design methods is that they have been developed considering vibration control only; hence they cannot be applied directly to energy harvesting.

Based on previous works and issues encountered in this study, a high quality energy harvester using a tuned dual-mass damper system and the One-Air-Gap linear alternator [3], named hereafter Tuned Mass Generator (TMG), has been proposed. The proposed parameter design method for this original TMG considers the purpose of energy harvesting to achieve greater power generation from bridge vibration. This feature has been validated by experiment on a trial bridge.

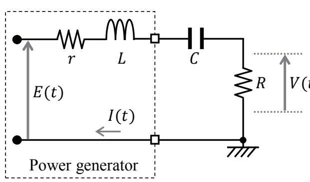

Fig. 1: Equivalent circuit of a linear electromagnetic transducer.

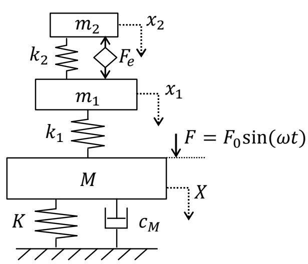

Fig. 2: Analysis model of TMG.

2. Comparison of Single-Mass and Dual-Mass Systems

When generators can produce a high damping ratio from electric power, dual-mass vibration energy harvesters can generate greater power than if single-mass. Second, by changing the tuning ratio, the dimensionless power spectrum is flexible to tuning in dual-mass systems. Hence a dual-mass TMG with a One-Air-Gap linear alternator [3] has been selected for this study.

3. Formularization of the Linear Electromagnetic Transducer

As shown in Fig. 1, an equivalent circuit has been introduced, to formularize the linear electromagnetic transducer. Experiments were performed to obtain the values for internal resistance r, inductance L and electromotive force coefficient k_{emf}.

4. Multi-Domain Parameter Design Method

The purpose of multi-domain parameter design is to maximize power generation and ensure robustness. Fig. 2 shows the analysis model. Electric power generation is calculated using various combinations of TMG parameters such as frequency ratios and equivalent electrical damping ratio. The sequence of analysis is then reiterated until the maximum electric power generation is obtained.

5. TMG Installation and Application to Trial Bridge

The trial bridge is a three span continuous steel truss bridge, located on the Chuo Express way, Japan. The target frequency f_c was decided as 14.15 Hz, and parameters were designed using the proposed parameter design method. Bridge vibration energy harvesting depends highly on traffic density, and so TMG can harvest more energy when there is a continuous flow of heavy vehicles passing over the bridge. However electric power generation depends mainly on vehicle speed and weight than traffic density. Fig. 3 shows the harvesting energy for each hour during the 24 hour measurement period. Experimental results have clarified that a robust parameter design is essential to ensure TMG can harvest variable bridge vibration energy. In addition, if harvesting power can be controlled, TMG could monitor bridge vibration frequencies.

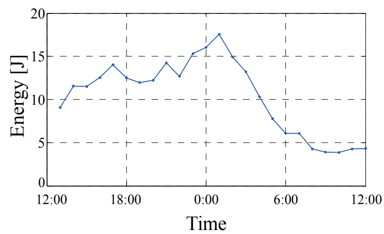

Fig. 3: Maximum power generation.

6. Conclusions

Dual-mass systems have several advantages over single-mass systems for power generation. Based on this finding, a high quality bridge vibration energy harvester, named Tuned Mass Generator (TMG), has been proposed. Required TMG characteristics have been formularized using the equivalent electric circuit of the linear electromagnetic transducer, which makes use of the unused reserve of energy in damper systems to harvest energy. In addition, a multi-domain parameter design method has been developed to tune the TMG. Experimental results from the trial bridge show that for effective energy harvesting, first, it is essential to determine the relationship between the required characteristics for the linear electromagnetic transducer, and second, the TMG uses a robust parameter design. Finally, there is also potential for the proposed TMG to be further developed so that if the relationship between battery voltage and energy harvested can be controlled, it could even monitor bridge vibration frequencies.

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