

Field Measurement-Based Analysis of Impulsive Bridge Vibrations for Energy Harvesting

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Summary:

This work presents a harvester-oriented analysis of field-measured bridge vibrations. Impulsive events were detected using a dual-threshold envelope method and classified by burst organization. Velocity-weighted spectral analysis was used to identify harvester-relevant low-frequency content. The results show that useful mechanical input is governed more by burst morphology and low-frequency structural response than by the highest acceleration peaks. These findings support the selection of harvester bandwidth, tuning frequency, and impact-response design concepts. This work was conducted within the SBMuW project at HafenCity University Hamburg

Keywords: Field vibration measurement, impulsive events classification, velocity-weighted STFT, energy harvesting, burst morphology

Background, Motivation and Objective

Vibration energy harvesting offers a promising route to power low-power sensing nodes for structural health monitoring, particularly in bridge and transport infrastructure where battery replacement is difficult. Piezoelectric harvesters are attractive for this purpose because they can convert local mechanical vibration into electrical energy and support self-powered monitoring systems [1,2]. However, their performance depends strongly on the actual vibration source, including amplitude, frequency, duration, direction, and event morphology. Therefore, vibration intensity alone is insufficient for harvester design. This work analyzes impulsive vibration events measured at a bridge expansion joint, classifies their time-domain morphology, and extracts harvester-relevant spectral features to support the selection of suitable energy harvesting concepts.

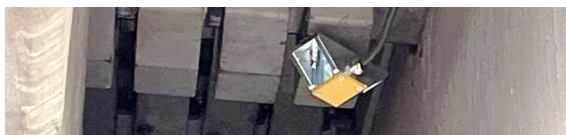


Fig. 1. Kionix KX134-1211 accelerometer module with a ± 8 g range and a bandwidth of approximately 8 kHz, mounted on the expansion joint of Köhlbrand Bridge in Hamburg, Germany

Description of the New Method or System

This work proposes a harvester-oriented method for analysing bridge expansion-joint vibrations (Fig.1.), based on one week of daytime measurements with 60 s continuous recordings collected every 30 min. Impulsive events are

detected by a dual-threshold envelope method and classified by burst organization using a data-driven characteristic burst time. By combining time-domain morphology with velocity-weighted spectral analysis, the method links real impulsive vibration features to harvester bandwidth, tuning frequency, and response design requirements.

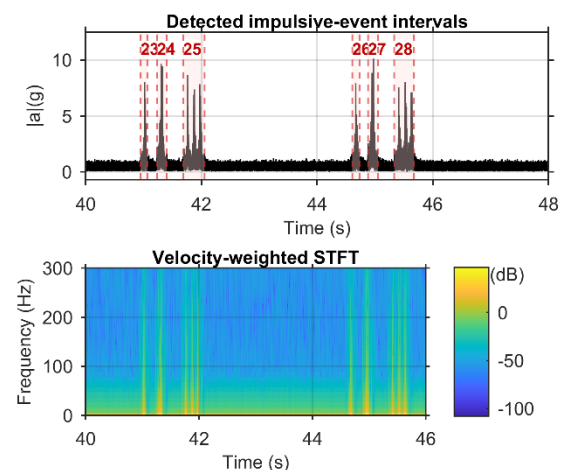


Fig. 2. Fig. 2. Impulsive-event intervals and velocity-weighted STFT. Detected intervals in $|a|$ are compared with the corresponding velocity-weighted time-frequency response.

Results and Discussion

The measured expansion-joint response is dominated by intermittent impulsive events rather than continuous stationary vibration. As shown in Fig. 2, these events appear as short high-amplitude intervals in the resultant acceleration $|a|$, while the velocity-weighted STFT shows that the harvester-relevant response is concentrated in a

lower-frequency band rather than at the highest acceleration peaks. This is consistent with Fig. 5, where Type2 and Type3 events show similar dominant velocity-weighted spectral content despite different burst organizations.

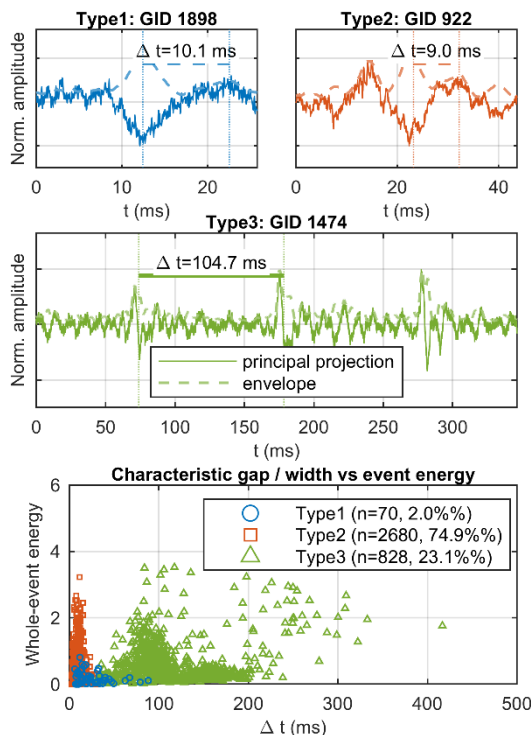


Fig. 3. Time-domain classification of impulsive events. Representative waveforms and the Δt -energy distribution distinguish single-burst, continuous multi-burst, and discrete burst-cluster events.

The time-domain classification in Fig. 3 shows that the events are not uniform single-burst responses. Continuous multi-burst events dominate, while discrete burst clusters form another important group. Together with the envelope similarity shown in Fig. 4, this suggests that laboratory reproduction should use representative event templates, including single bursts, continuous multi-burst events, and discrete burst clusters, rather than only single impacts or steady sinusoidal excitation.

These results provide direct implications for harvester design. The low-frequency velocity-weighted energy concentration supports resonant cantilever harvesters with adjustable proof mass as a basic option. The observed spectral spread and different burst organizations suggest multi-degree-of-freedom systems or cantilever arrays for broader bandwidth. The intermittent impulsive excitation further motivates impact-excited, stopper-assisted, or nonlinear bistable/multi-stable designs, while weak background vibration and event tails may benefit from strain-amplifying structures such as cymbal-type transducers or auxetic substrates. [3,4]

Overall, the expansion-joint vibration should be considered as low-frequency structural response triggered by impulsive events. Suitable harvester concepts should therefore account for event morphology, burst organization, velocity-weighted spectra, and bandwidth.

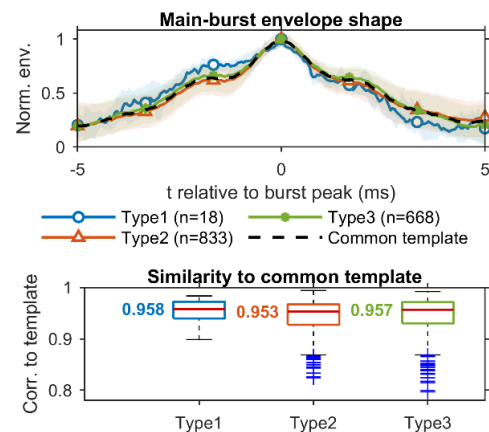


Fig. 4. Burst envelope similarity based on 3000 randomly sampled bursts from all measurement files.

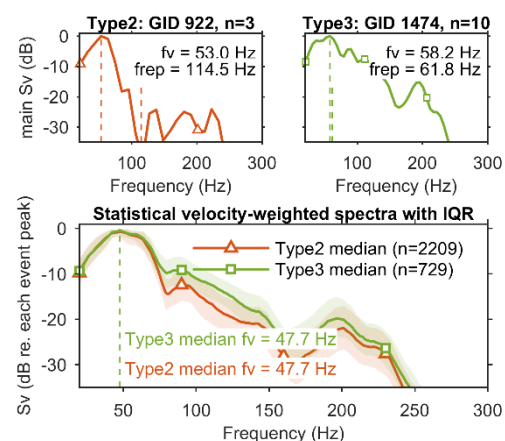


Fig. 5. Peak-centred burst spectra of Type2 and Type3 events. Example spectra show f_v and f_{rep} , while the lower panel summarizes all burst windows identified around main envelope peaks. Both types show a dominant velocity-weighted band around 50 Hz.

References

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