SHM: Railroad bridge monitoring using Dragonfly® piezoelectric strain gauge

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Abstract

Structural Health Monitoring (SHM) applied to civil structures such as bridges, high-rise towers, and electricity pylons can help plan their maintenance, detect damages or un-expected events, and extend their remaining operating lifetime. Typical sensors for this field have limitations in terms of sensitivity, drift, and reliability. Dragonfly® new piezoelectric strain gauges, with a resolution three order of magnitude over classic sensors, solve these issues and enable new applications. This paper presents the implementation of Dragonfly® sensors on a railroad bridge. With a single sensor, it has been possible to identify the bridge girder first two resonance using ambient noise, train passage loading for fatigue-life analysis, train passage reproducibility, and pedestrian passage on the walkway. A complete comparison with classic strain gauge is detailed.

Key Words

Piezoelectric, Structural Health Monitoring, Bridge monitoring, Strain gauge, Fatigue-life, Event Detection

1 Introduction

In France, 25% of the existing bridges are reaching their expected service life. Moreover, 79% of the total park present structural defects that need to be assessed [1]. Monitoring the critical structures becomes essential to prevent a catastrophe. The present study concerns the usage of Dragonfly® (DGF) piezoelectric strain gauges for Structural Health Monitoring (SHM) of a railroad bridge.

Metallic foil strain gauge (SG) and vibrating wire are the historic sensors used to measure strain on civil structures. However, civil structures are designed to undergo little deformation in service (0.1-50 µdef). Both SG and vibrating wire are limited by their resolution around 1 µdef. Moreover, they are known for their DC drift over time, which complexifies long term monitoring. There is therefore a need for more sensitive and less prone to drift sensors in the time domain.

1.1 Dragonfly sensors

Dragonfly® sensors consist in an extremely thin piezoelectric ceramic packaged in a flexible PCB and pre-wired with a SMA connector. The flexible sensor is glued with cyanoacrylate glue to the object to be studied. The specificity of this sensor is that it enables measurements down to 0.01 µdef.

Like all sensors based on piezoelectricity, Dragonfly® are dynamic sensor by nature. With adequate electronics, they can measure slow events (up to 30 seconds) but will always return back to zero. Dragonfly sensor are therefore insensitive to slow thermal expansion, a historical issue of structure monitoring.

1.2 The railroad bridge studied

The bridge monitored is located in Grenoble, France, in proximity to the train station. It has 3 railways and an auxiliary walkway accessible to the public. The bridge is a simple girder bridge with 12 steel beams. Trains are circulating in both directions (towards Grenoble and Lyon).

Figure 1: The railroad bridge monitored. The external metal girder on which the sensors are installed is visible.

Figure 3: Dragonfly sensor before protective layer installation

2 Sensing strategy

A standard strain gauge and a Dragonfly sensor have been installed on the external girder of the bridge, on the opposite side of its walkway. The sensors are installed close to a girder support element.

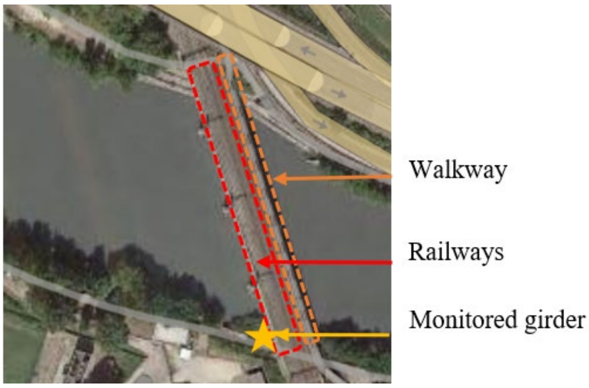

Figure 2: Monitoring area, railways and pedestrian walkway configuration.

The surface was polished and cleaned to ensure proper bonding of both sensors. Both sensors are measured by a Dewesoft IOLITE 6-STG system. A video camera was installed for the analysis of train passage.

2.1 Strain Gauge measurement setup

A standard HBM 120Ω strain gauge has been installed and protected with ABM75 by HBM. The strain gauge is measured in quarter bridge configuration.

2.2 Dragonfly installation

A Dragonfly® passive sensor has been installed parallel and in close proximity to the strain gauge. The same external ABM75 protection was applied. Signal was measured with a charge amplifier. In this configuration, the lower cut-off frequency is limited by the amplifier at 0.01 Hz.

3 Results & analysis

3.1 Bridge resonance

First acquisition was made while the bridge was at rest with no passage. The signal Power Spectral Density (PSD) of the ambient noise is presented below for both Dragonfly® and SG. The only peaks on the SG are related to ambient electrical grid radiation (50Hz). On the Dragonfly®, two sharp peaks (16 and 60Hz respectively) can be attributed to the girder resonance modes. Tracking eigenfrequencies of structures is often used for structure damage monitoring [2-4]. Though it is typically done though accelerometers, the data can now be obtained through the high sensitivity of the piezoelectric strain gauge.

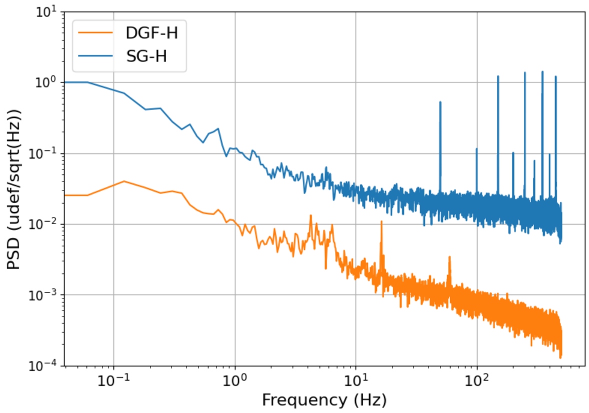

Figure 4: PSD of the bridge at rest with modal resonance visible on Dragonfly® (DGF)

3.2 Strain gauge signal processing for temporal analysis

SG signal received consequent ambient radiation noise produced by the nearby electrical lines. A low-pass first-order IIR filter at 45 Hz has been applied to the SG for sensor comparison. Moreover, DC drift from initial sensor calibration was removed for the SG.

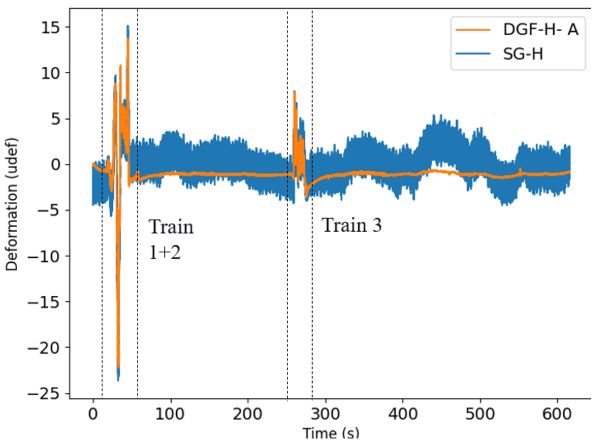

Figure 5: Signal after strain gauge DC drift compensation and filtering

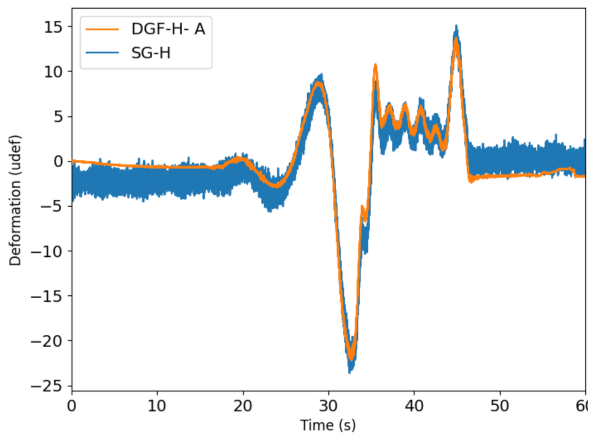

Figure 7: Dragonfly® (DGF) and SG signal while 2 trains pass on the bridge (Train 1 and 2)

3.3 Train passage loading

After signal treatment, excellent agreement between the strain gauge and the Dragonfly is obtained as demonstrated in figure 6. For the train in the figure below, the maximum load is 8.77 µdef and occurred at the locomotive wagon passage over the sensor location. The passage of 8 wagons can be identified.

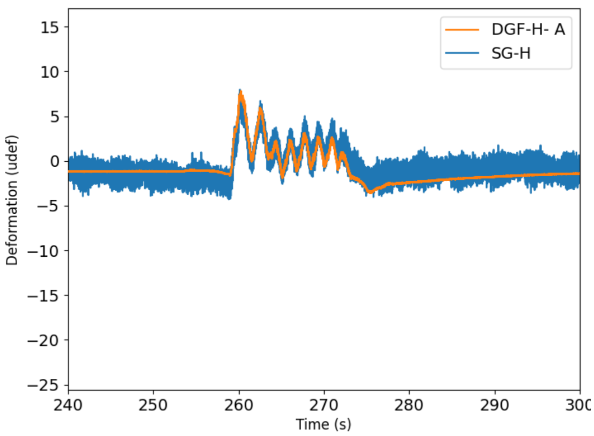

Figure 6: Passage of a passenger train (Train 3)

Rainflow load counting is a widely used method to calculate the structure remaining service lifetime [5-6]. In these studies, strain amplitude measured with classic strain gauge is small (<10 µdef). The SG resolution in the best condition is around 1 µdef. SGs have to be installed on areas of the bridge undergoing a maximum of deformation to have some chance of success. As the signal-to-noise ratio is greatly increased with Dragonfly®, sensor installation can be done in convenient and accessible bridge area where deformation is smaller.

On figure 7, two trains passed simultaneously on the bridge on different railways. It resulted in a very different signal pattern for event identification.

3.4 Pedestrian passage identification

Large strains such as the ones created by trains are useful to measure the fatigue life of a structure. However, it is interesting to monitor events of smaller amplitude for surveillance applications. The dragonfly resolution being very low (0.01 µdef), the strain generated by a single individual passing on the bridge is easily measured. The figure below shows the peak-to-peak signal intensity increasing as walker passes over the walkway. It is notable that even though sensors are installed on the girder on the opposite side of the walkway, strain amplitude is sufficient for event identification.

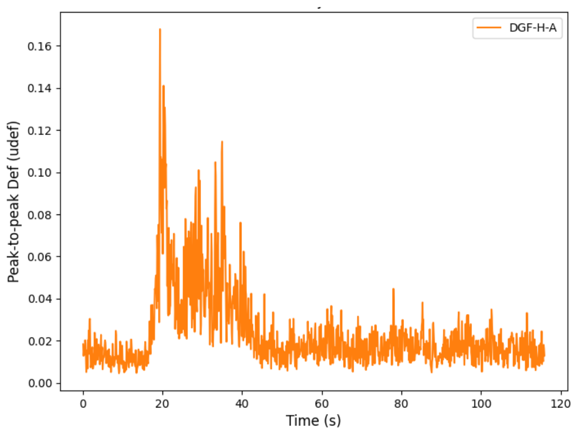

Figure 8: Signal peak-to-peak for pedestrian passage on the walkway.

3.5 Train passage reproducibility

The graph below presents the passage of two different trains, with the same number of wagons, same direction and departure railway. An exact superposition of the signals can be seen for the Dragonfly. For this measure, a IEPE version of the Dragonfly® was used. This sensor is compatible with IEPE acquisition systems and does not require a charge amplifier. The IEPE acquisition adaptor lower cut-off frequency is 0.16Hz, thus modifying the signal shape.

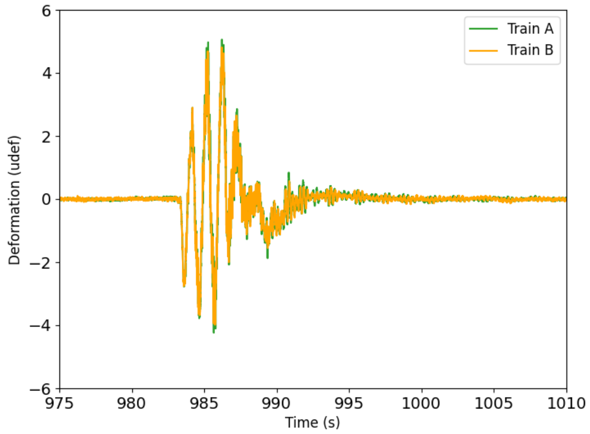

Figure 9: Dragonfly® (DGF) for 2 different passenger trains of 5 wagons coming from the train station. Train B time has been shifted for superposition.

4 Conclusion

Dragonfly piezoelectric strain gauge has been tested in the context of civil structure health monitoring. Structure resonance frequencies have been measured using the ambient noise, which enables a follow-up of the monitored structure integrity. Events causing the structure to fatigue such as train passage have been quantified. The values are in excellent adequation with conventional metallic foil strain gauge. The higher SNR of dragonfly enables them monitoring of very precise events, from train repeatability to pedestrian passage detection.

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