Novel Photonic Vibration Sensor for In-situ Data Acquisition

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Abstract

Micatu, Inc. has developed the Photonic Vibration Sensor (PHOVIS) for high performance, *in-situ* data acquisition. PHOVIS (**Fig. 1**) provides a direct optical interferometric signal measurement of vibrational displacement and frequency, in contrast to conventionally available vibration sensors. Measurement of vibrational displacement amplitudes at high resolution (sub-micron) is possible in both time series and FFT frequency data (< to 10 kHz) necessary for precise characterization of Condition Monitoring Signatures (CMS) for wind turbines and industrial machinery. In addition, PHOVIS exhibits no noise due to mechanical transfer function, thereby providing for a wide dynamic range (0.01g to 10g) and unprecedented sensitivity, and accuracy capable of measuring transients.

PHOVIS features the novel use of monolithic, solid optical components, providing a simple package and detection method in which there are no electronic components or electrical power in the sensor head making the photonic vibration sensor impervious to Radio-Frequency (RF) and Electromagnetic Interference (EMI).

Tests of PHOVIS were conducted at the National Renewable Energy Laboratory (NREL) as part of the Gearbox Reliability Collaborative (GRC) project analyzing generator disengagements to simulate grid disconnections. For these experiments, dynamometer speed decreased linearly while the drivetrain torque oscillated as it was being damped. PHOVIS installed on the gearbox monitored these events, providing real-time amplitude and spectra data, with precise (+/-1%) characterization of all transients and harmonics of the frequency signature within the sensor bandwidth.

Introduction

PHOVIS uses a cantilevered Fabry-Perot Etalon (FPE) to detect motion, such as vibration.

PHOVIS Principle of Operation:

A FPE comprises two parallel reflective surfaces with a small gap or cavity. When a collimated optical light beam is passed into the FPE at an entry point, it does so at a fixed angle of incidence. It then reflects multiply between the reflective surfaces along the optical path length of the FPE cavity**.** The successive reflected beams within the optical cavity exhibit an Optical Path Difference (OPD). Movement of the FPE changes the angle of incidence of the light, thus changing the OPD. These changes to the OPD cause constructive and destructive interference of the light, resulting an intensity modulation due to interference of light within the FPE. This times series intensity modulation can be used to calculate a frequency spectrum (FFT) of vibration.

In PHOVIS, a light source provides collimated light to the sensor via a fiber optic cable. Light passes through the sensor and is transmitted back to an optoelectronic data acquisition and processing unit. Thus, the PHOVIS sensor itself is completely passive, receiving only light, and having no onboard electronics.

Advantages of PHOVIS

Due to the nature of the cantilevered FPE, PHOVIS is highly sensitive and accurate. Any displacement, vibration, acceleration, or transient feature is resolvable to the limit of detection of the optical power signal and associated detection electronics. Therefore, its sensitivity is less than 0.1% of peak vibration amplitude, at least an order of magnitude improvement over typical accelerometers including MEMs, piezoelectric, or capacitive type sensors.

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Methods and Materials

A series of experiments to assess PHOVIS' performance were conducted at Micatu's facility in New York, and at the Gearbox Reliability Collaborative (GRC) at National Renewable Energy Laboratory (NREL), in Colorado. Materials used included Micatu's PHOVIS sensor and m410 processor, a comparative PCB piezotronics accelerometer model: 352C33, Model 480E09 ICP sensor signal conditioner (PCB) , unity gain, and the Model DI-1110 Data Acquisition USB DAQ (DATAQ Instruments).

Micatu and NREL Experiments

Experiments at NREL were conducted on the GRC drivetrain which has shaft speeds of 14.7 and 22.1 rpm. With a gearbox ratio of 81.491 the shaft speeds convert to generator speeds of 1,200 Rotations/Min (RPM) and 1,800 RPM (30 Hz) respectively.

Testing were performed on a 2.5-MW dynamometer at the National Wind Technology Center (NWTC). The dynamometer variable frequency drive and Non-Torque Load (NTL) system enabled the reproduction of field conditions, including static and dynamic thrust, vertical force and lateral force to the adapter couplings in front of the GRC main bearing. For generator engagement: the generator was operating at full speed and came online to approximately 20% power.

For generator disengagement: the generator was operating at full speed and full power and was intentionally disconnected and went offline.

Results

Fig 2 shows the response of PHOVIS in comparison to PCB accelerometer model 352C33 at 30 Hz (1800 RPM).

Fig 3 shows graphs of of the frequency spectrum (0-2500Hz) during the generator engagement experiment for sensor VA which is placed on the high-speed gearbox. Graph A shows the vibration when the system is running at 1800RPM at 0% power and B shows the results after the generator is engaged at 25% power at 1800RPM. Inset shows drivetrain torque and speed during generator engagement event.

Fig. 4 shows graphs of the frequency spectrum (0-2500Hz) during the generator engagement experiment for sensor VA which is placed on the high-speed gearbox. Graph A shows the vibrations when the system is running at 1800RPM@0% power and B shows the results after the generator is engaged at 25% power@ 1800RPM. Inset shows drivetrain torque and speed during generator disengagement event

Figure 1

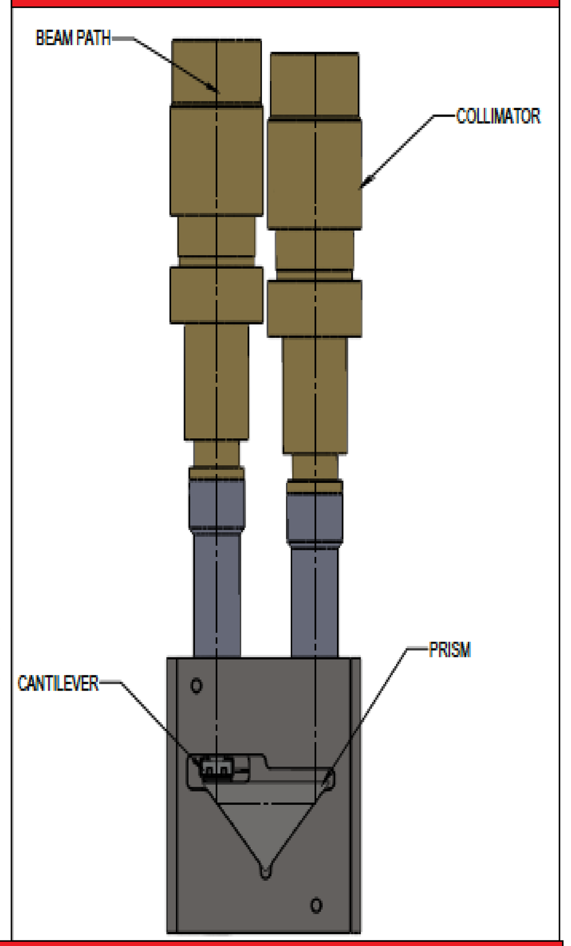


Figure 2

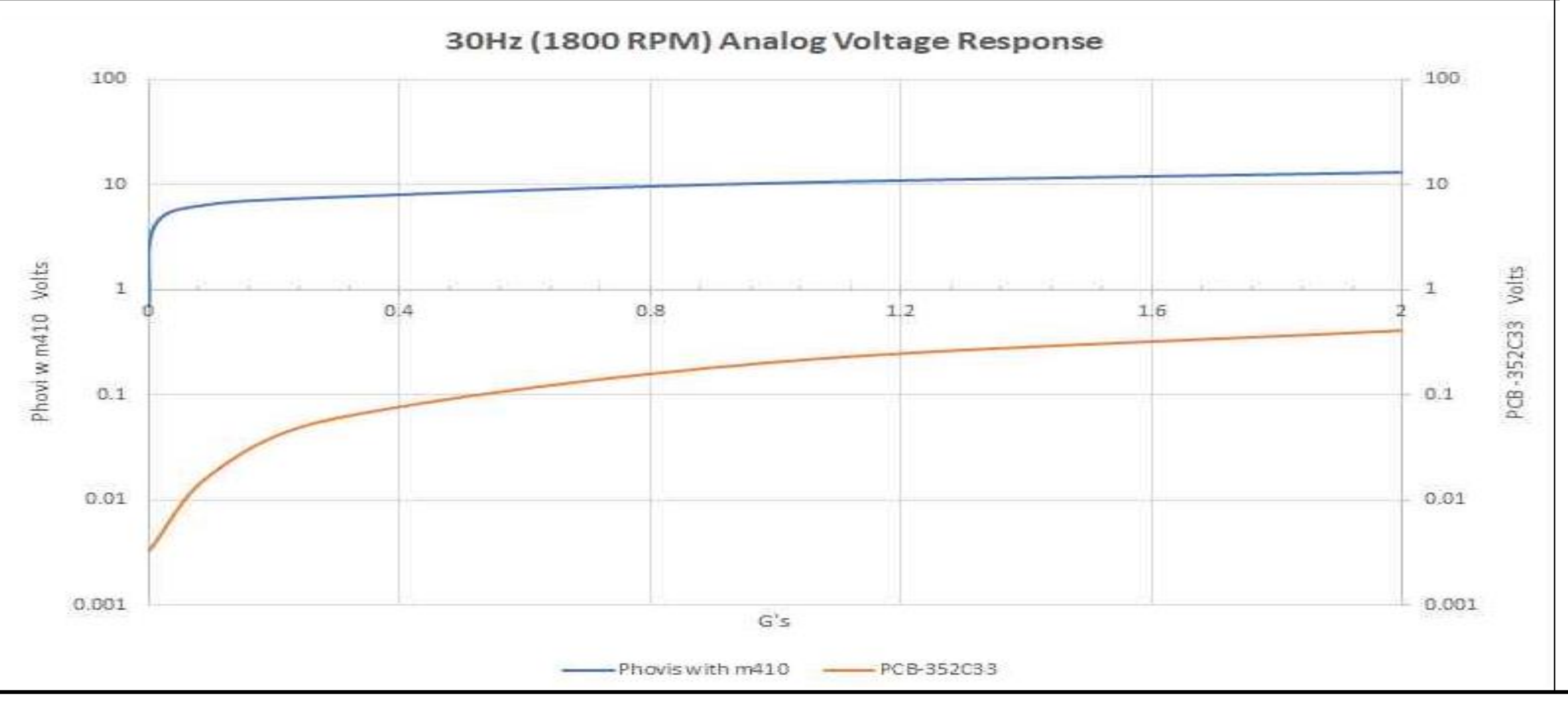


Figure 3

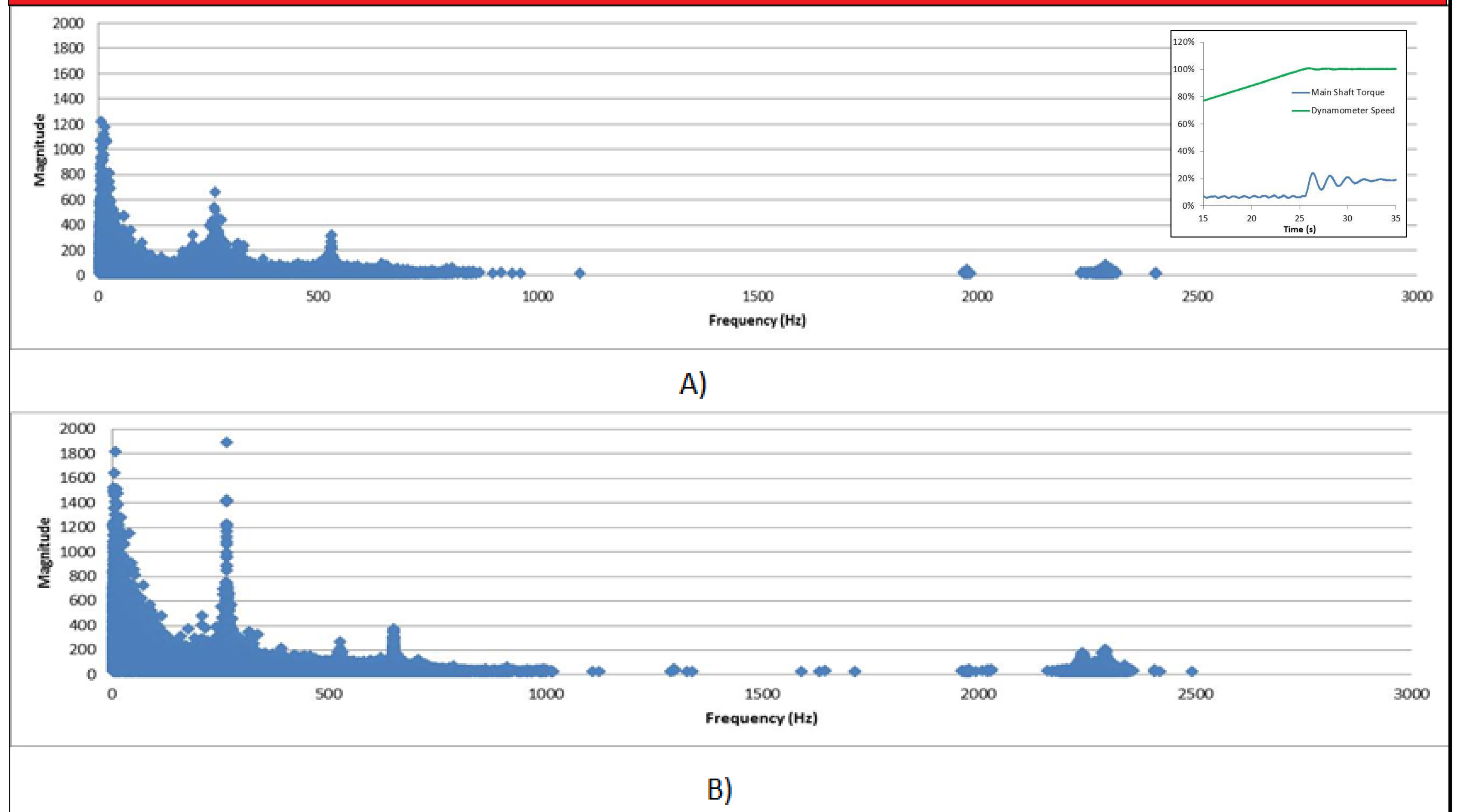
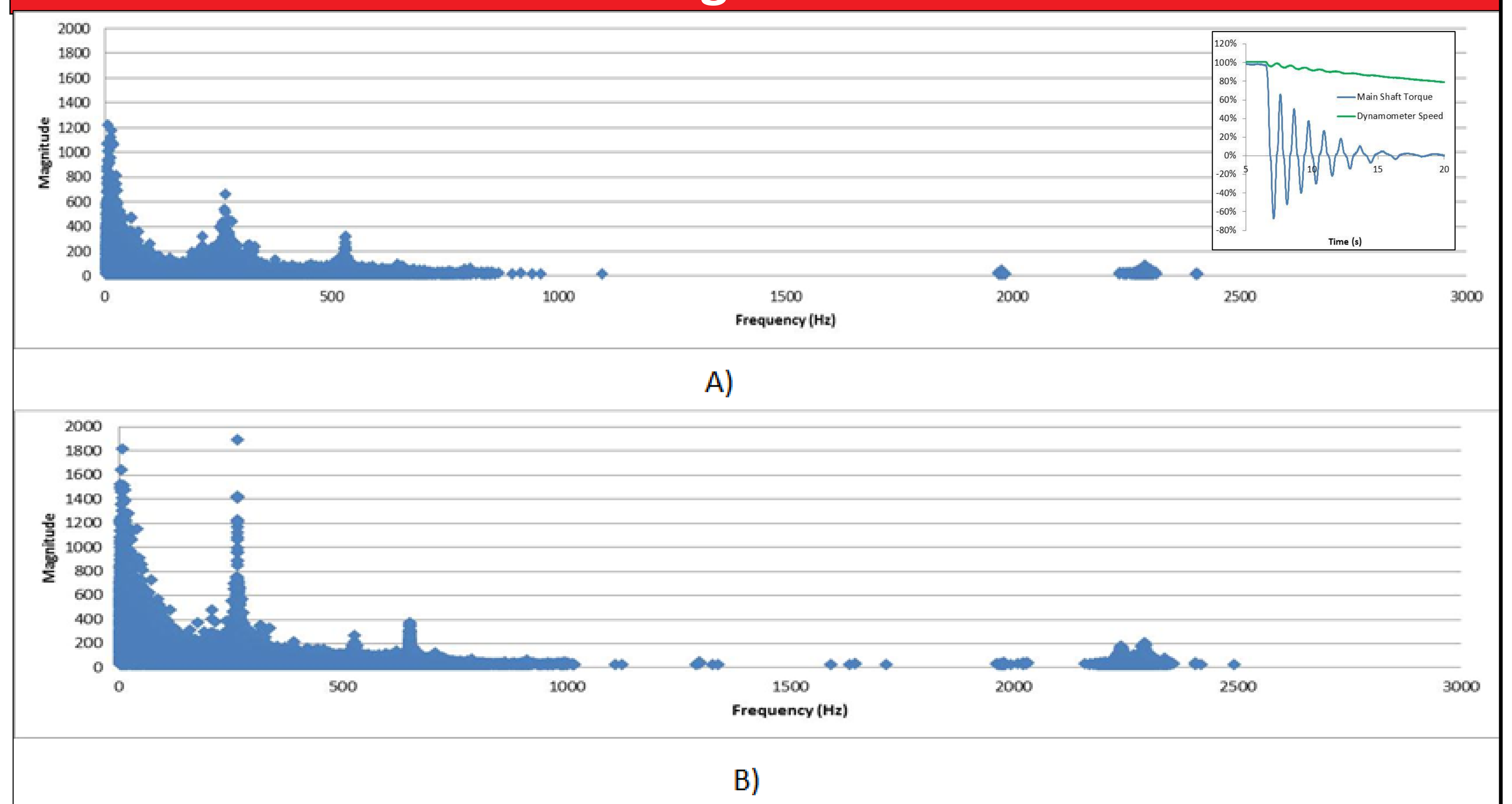


Figure 4



Discussion

1) In comparison of the PHOVIS-m410 vs PCB system, the amplitude (analog voltage) response at 30 Hz is more than an order of magnitude greater with a much flatter more sensitive profile going to low amplitude vibrations (<1g).
2) Low frequencies and amplitudes are important for measuring harmonics and transients relevant to mass, load bearing, and cavitation in wind turbines and rotating machinery. Specific examples are the generator/gearbox engagement and disengagement events.
3) Based on the dynamometer data, FFT spectra at low frequencies are sensitive indicators of CMS events.
4) In totality, the PHOVIS-m410 system has greater (an order of magnitude) sensitivity to harmonics and transients in potential wind turbine CMS events at multiples of the rotation (RPM) or equivalent blade frequency in Hz.

Conclusion

PHOVIS with m410 can be more sensitive than conventional (piezo) sensors particularly at low frequencies (<600 Hz), and can distinguish between engagement and disengagement events, which is evident in CMS like FFT signatures before and during those events.