Application of AtoN Telematics for Structural Health Monitoring

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IALA ENG1 St Germain-en-Laye, France 2014-11-17

Problem

- Structural stability of certain types of fixed AtoN platforms is degrading at less predictable rate than others
- Stability of lattice masts and seabed-embedded poles is subject to degradation due to wind and wave effects
- Cases of **fixed AtoN platforms collapsing under wind or wave load, or introducing permanent focal plane inclination / misalignment of leading line centerline** due to material degradation are not too rare
- Restoration of a collapsed AtoN tends to be costly while safety of navigation is at least temporarily compromised

Solution

- Responding with slight deflection to external excitations like incident wind gusts and waves, slender pole-like structures tend to **vibrate at clearly defined natural frequencies** that shift when mechanical properties of the structure change (loose bolts or tensioners, weight loss)

- That effect presents opportunities for two-tiered structural health monitoring of AtoN platforms:
  - Monitoring of the **vibration magnitude** to estimate severity of conditions and detect trends like increasing deflections
  - Monitoring of the **frequency** of the dominating spectral component in order to detect mechanical changes

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Natural Frequency Appears When Excited

The resonance frequency depends on mass, stiffness and damping: dimensions, materials, weight, temperature, etc

Applicable Technologies

- **Structural Health Monitoring** (SHM) is nothing new
- Optimal for use on AtoN: an in-situ **acceleration sensor**
- **Analysis of vibration spectra using the Fast Fourier Transform (FFT)** may require too much **power** locally; it can be performed automatically at the server side after uploading the acceleration data from an AtoN site
- Cost savings come from tasking the **AtoN telematics infrastructure** with additional monitoring mission

Cybernetica AtoN SHM Solution

- Based on existing AtoN Telematics Controller **TelFiCon™** that uses a triaxial solid state acceleration sensor
- In-situ **acceleration measurement with local inclination angle calculation and raw data upload** to the telematics server since 2008 (GSM/GPRS/3G)
- Widely configurable measurement mission profile: from 1 minute hourly sessions to continuous acceleration measurement at **20 ms sampling interval**
- Temperature and voltage measurement as standard, AtoN **flasher functionality supporting FFI** is available

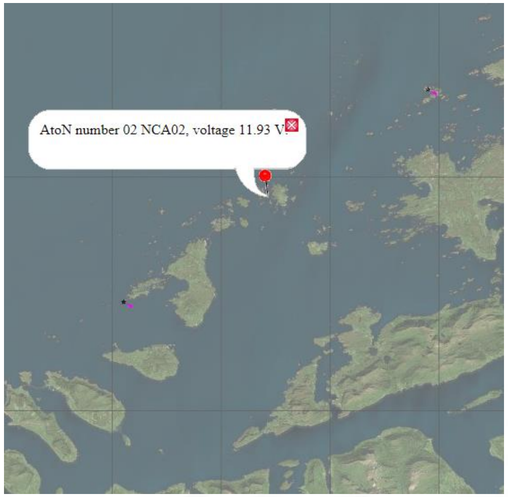
NCA01: Dirigens Lux AtoN at Småge

- Height 7.5 m above sea level, 2 m under water (high tide)
- Weight 100 kg
- Mount: embedded in seabed (or rock)
- Bearing structure: Ø 140 mm composite rod
- Type: Test object for a new maintenance free large composite HIB AtoN design

HIB = Hurtigbåtmerke med Indirekte Belysning,
High speed craft indirect lighting

NCA02: Dirigens Mini AtoN at Sandøy

- Height 6.5 m above sea level, 0.5 m below (high tide)
- Weight 60 kg
- Mount: embedded in seabed (or rock)
- Bearing structure: Ø 140 mm composite rod
- Type: Test object for a new maintenance free small composite HIB AtoN



HIB = Hurtigbåtmerke med Indirekte Belysning,
High speed craft indirect lighting

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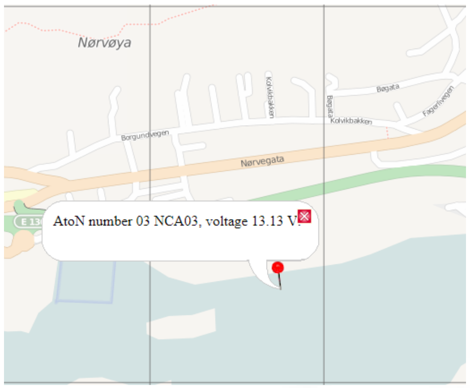
NCA03: Original HIB AtoN at Nørve

- Height 8.5 m above sea level, 1.5 m below at high tide
- Weight 500 kg
- Mount: embedded in seabed (or rock)
- Bearing structure: Ø 140 mm steel rod
- Type: Test object for the initial HIB design, large metal structure



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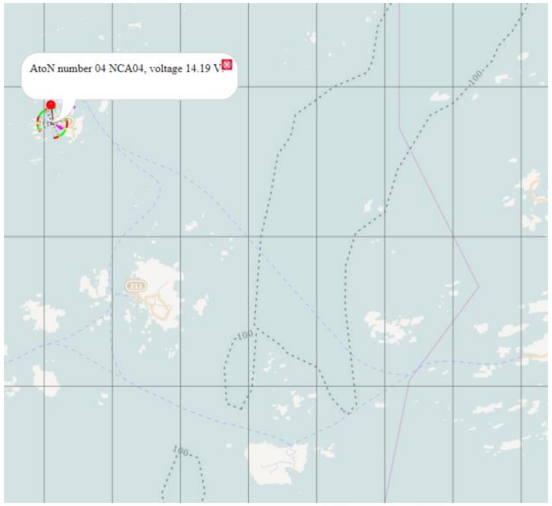
NCA04: Lighthouse at Husøyvågen, Ona

- Height 8 m above ground
- Weight 1500 kg
- Mount: 4 x threaded rods 48x1000 VZN
- Bearing structure: Composite GRP



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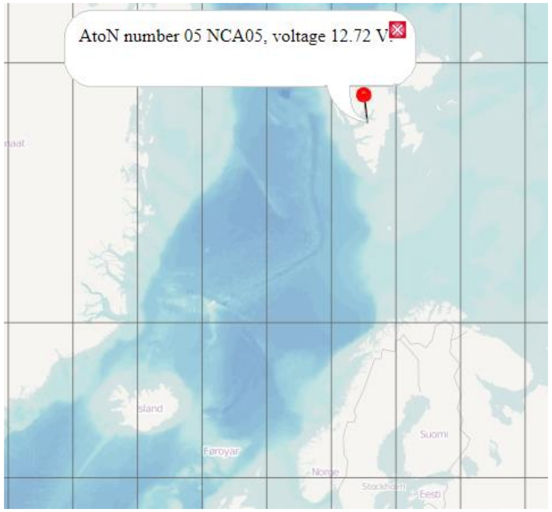
NCA05: Litus Lux Lighthouse on Svalbard

- Height 6.5 m
- Weight 500 kg
- Mount: 4 threaded rods 48x1000 VZN
- Bearing structure: Ø 800 mm Glass fiber re-inforced vinylester with a core of Divyncell
- Type: Test object for a new maintenance free generation of composite Lighthouses



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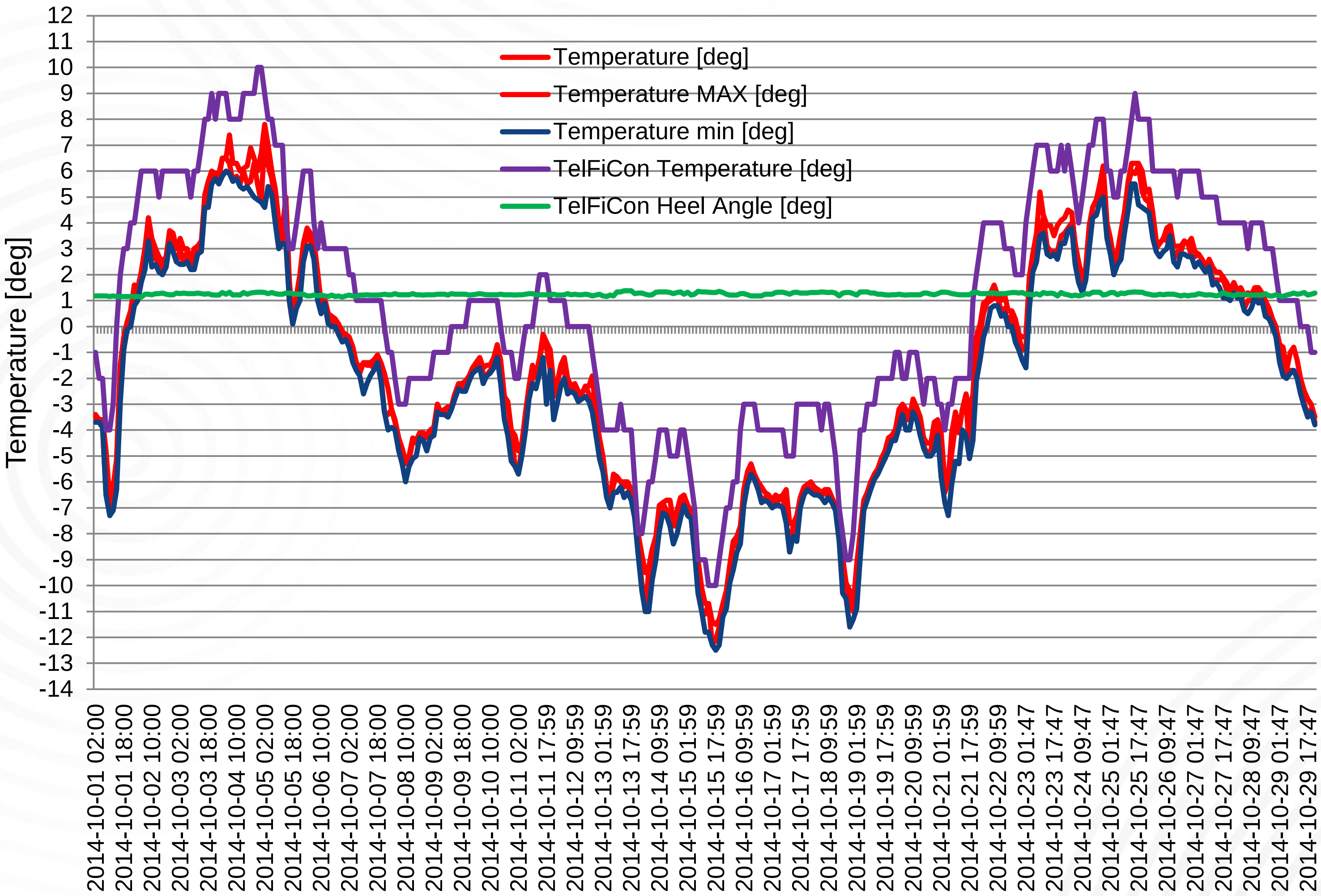
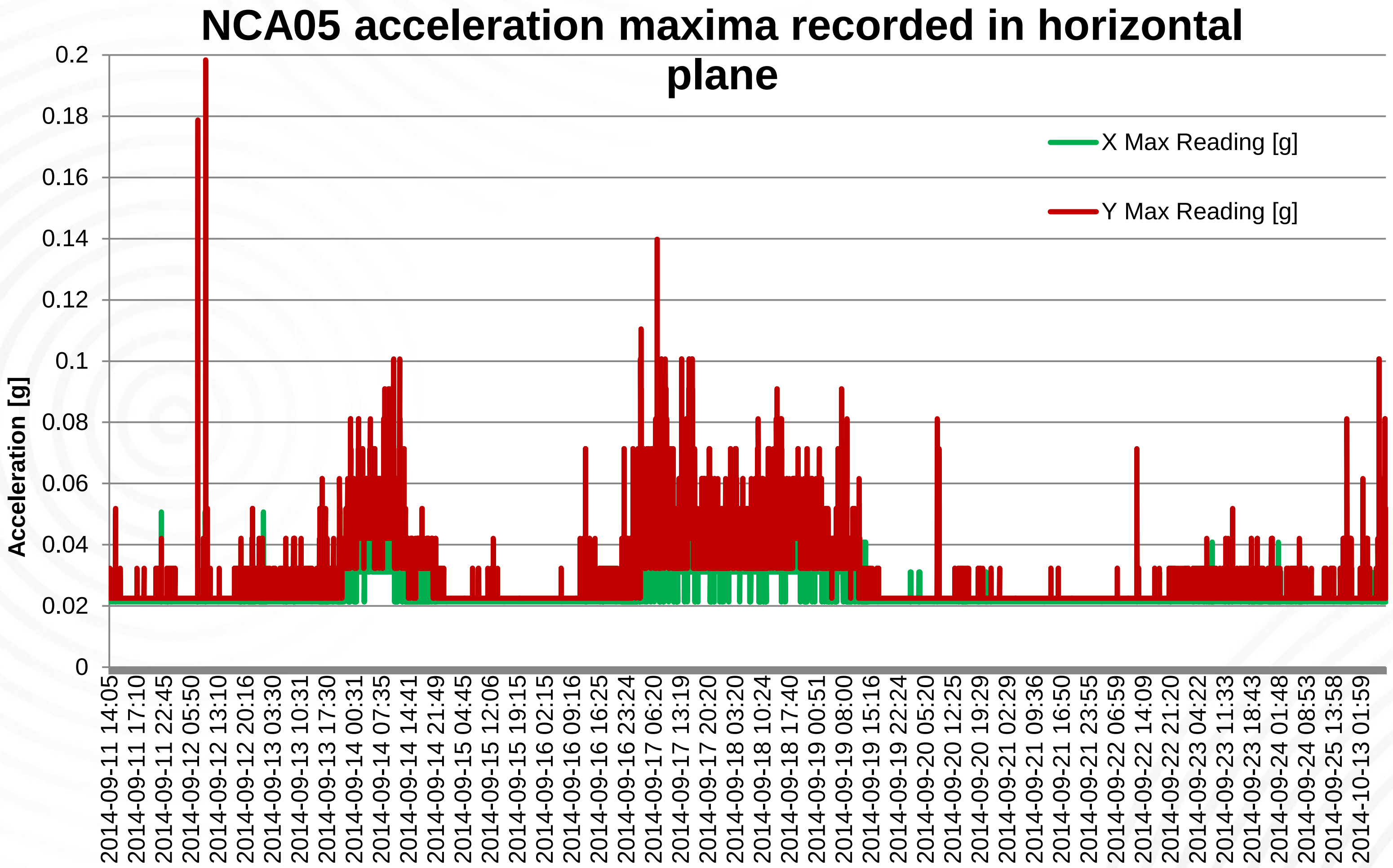
NCA05: Litus Lux Lighthouse Environment



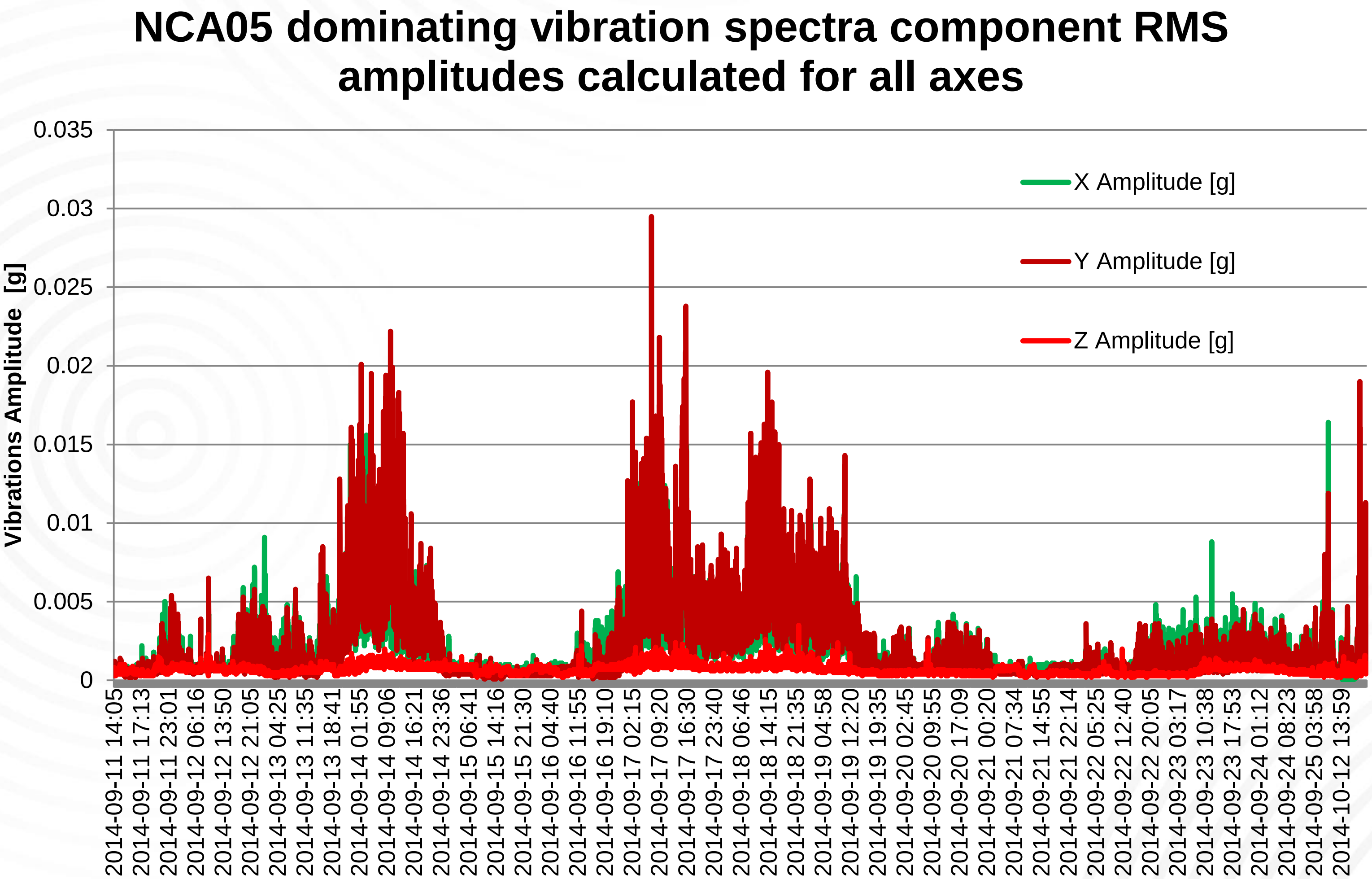
Inclination changes at 1.25° average are insignificant, within measurement uncertainty

NCA05: Litus Lux Lighthouse Acceleration



Incident wind gusts cause deflections of even stiff structures, up to 0.2g for NCA05

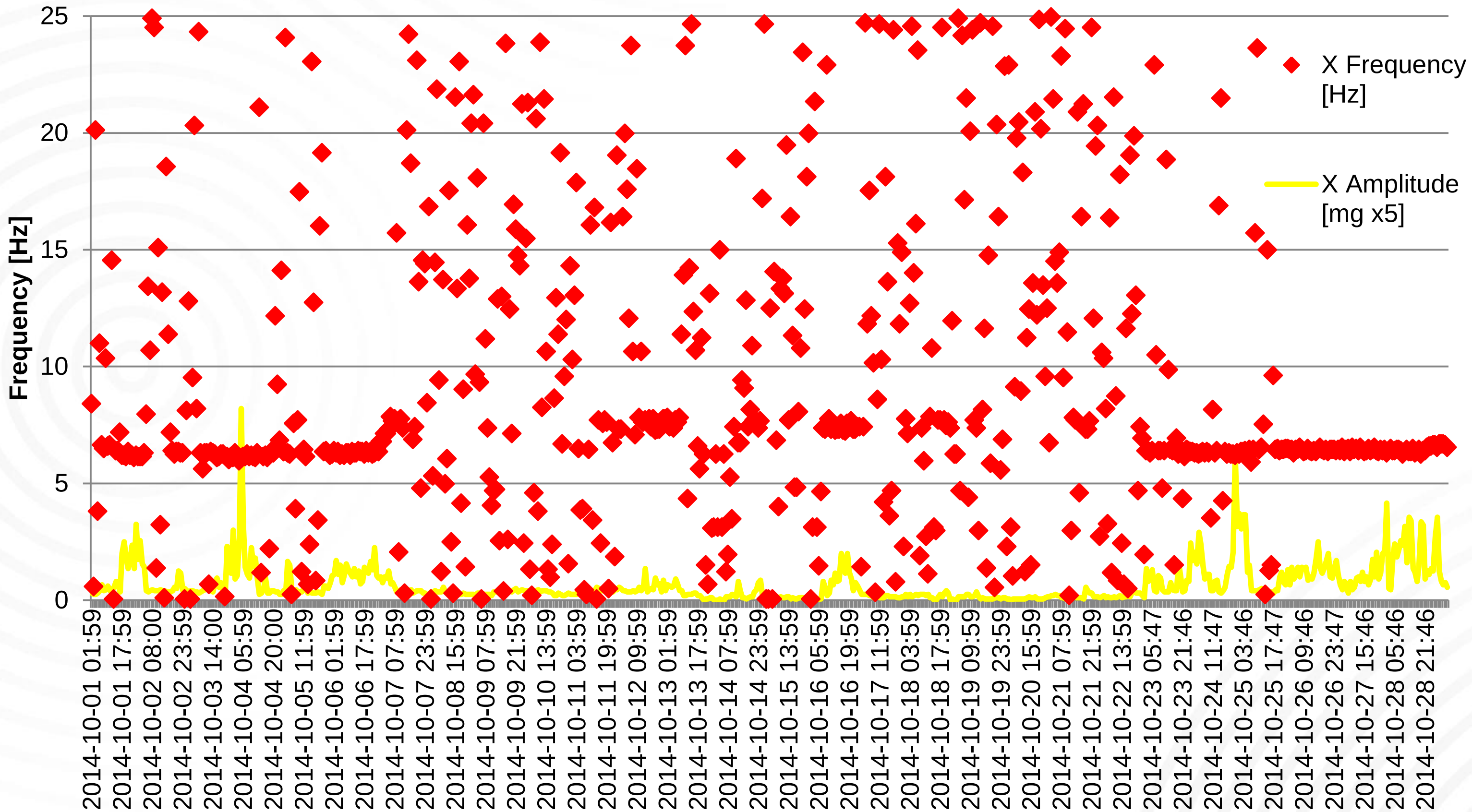
NCA05: Litus Lux Lighthouse Vibrations



Resulting wind induced vibrations are clearly detectable and in correlation with weather data

NCA05: Litus Lux Natural Frequency

X-Axis vibration frequency and magnitude (RMS)



Natural frequency ~7 Hz manifests itself when external excitation exceeds certain threshold

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NCA05: Vibration Amplitude & Frequency

Looking at nearly 2 months of dominant frequency (X) using FFT reveals very little changes

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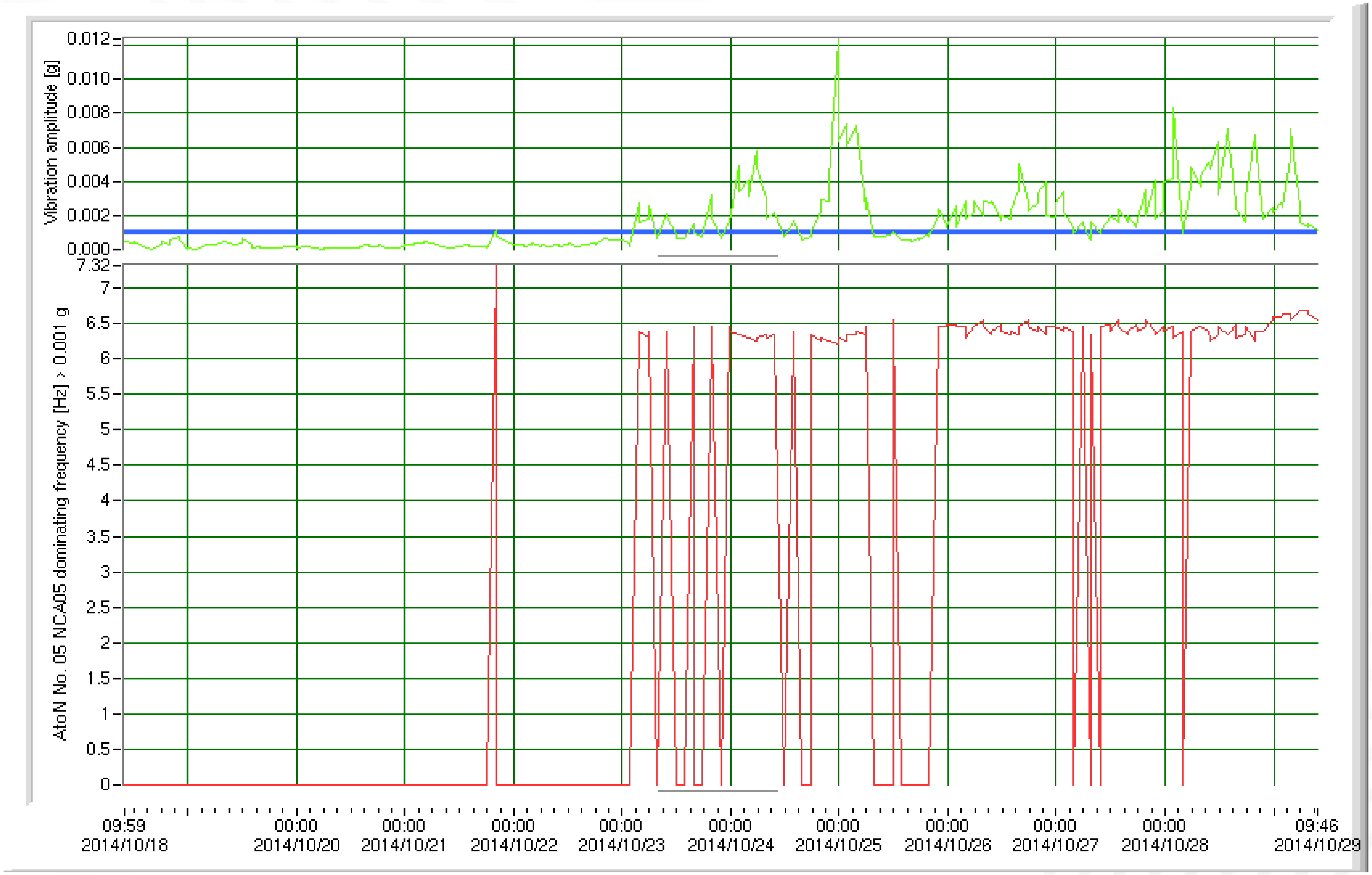
NCA05: Vibration Amplitude & Frequency



Setting a 1 mg threshold for displaying the results cleans away irrelevant noise at quiet times

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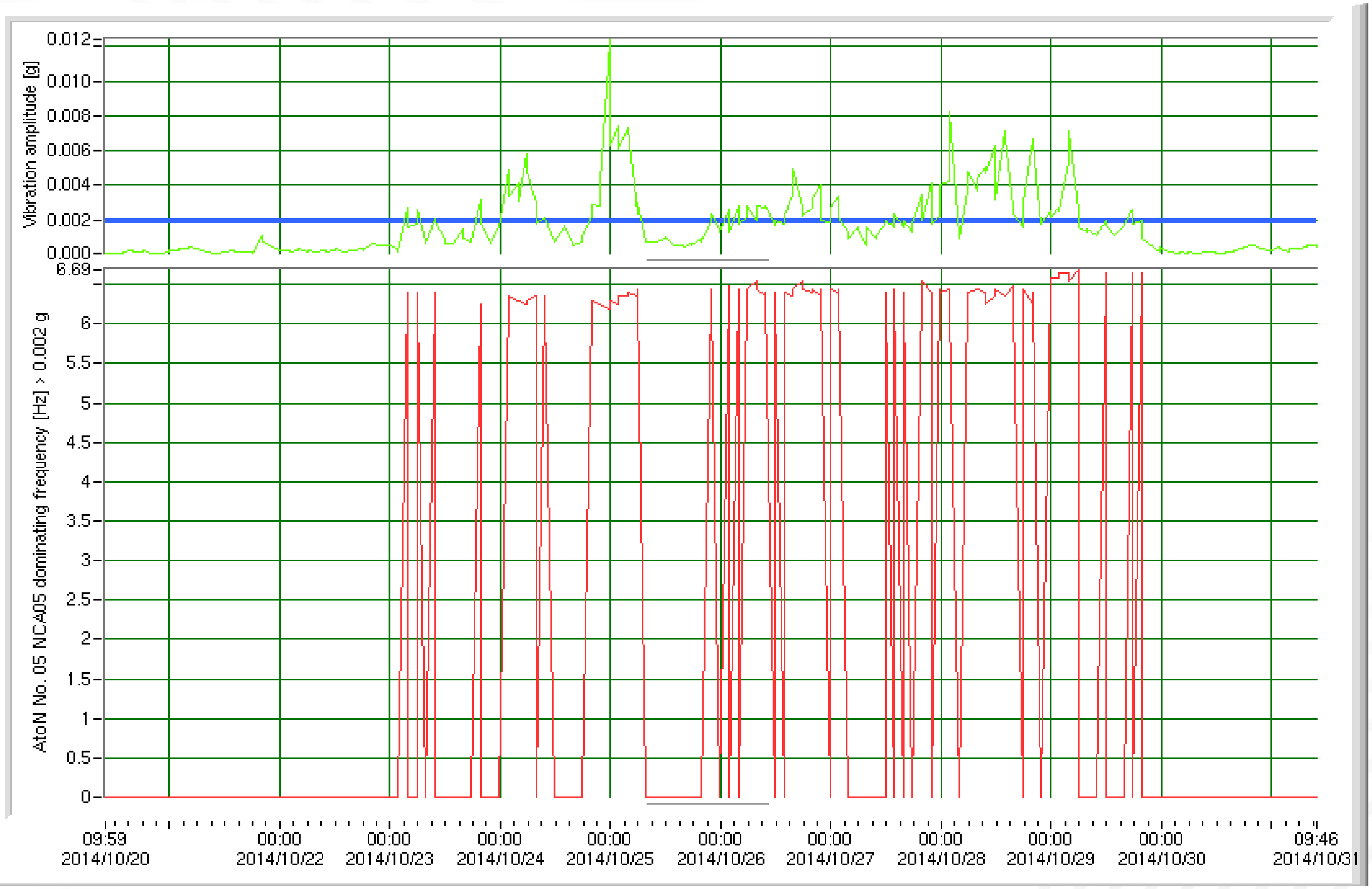
NCA05: Vibration Amplitude & Frequency



Setting a 2 mg threshold for displaying the results reveals NCA05 natural frequency trends

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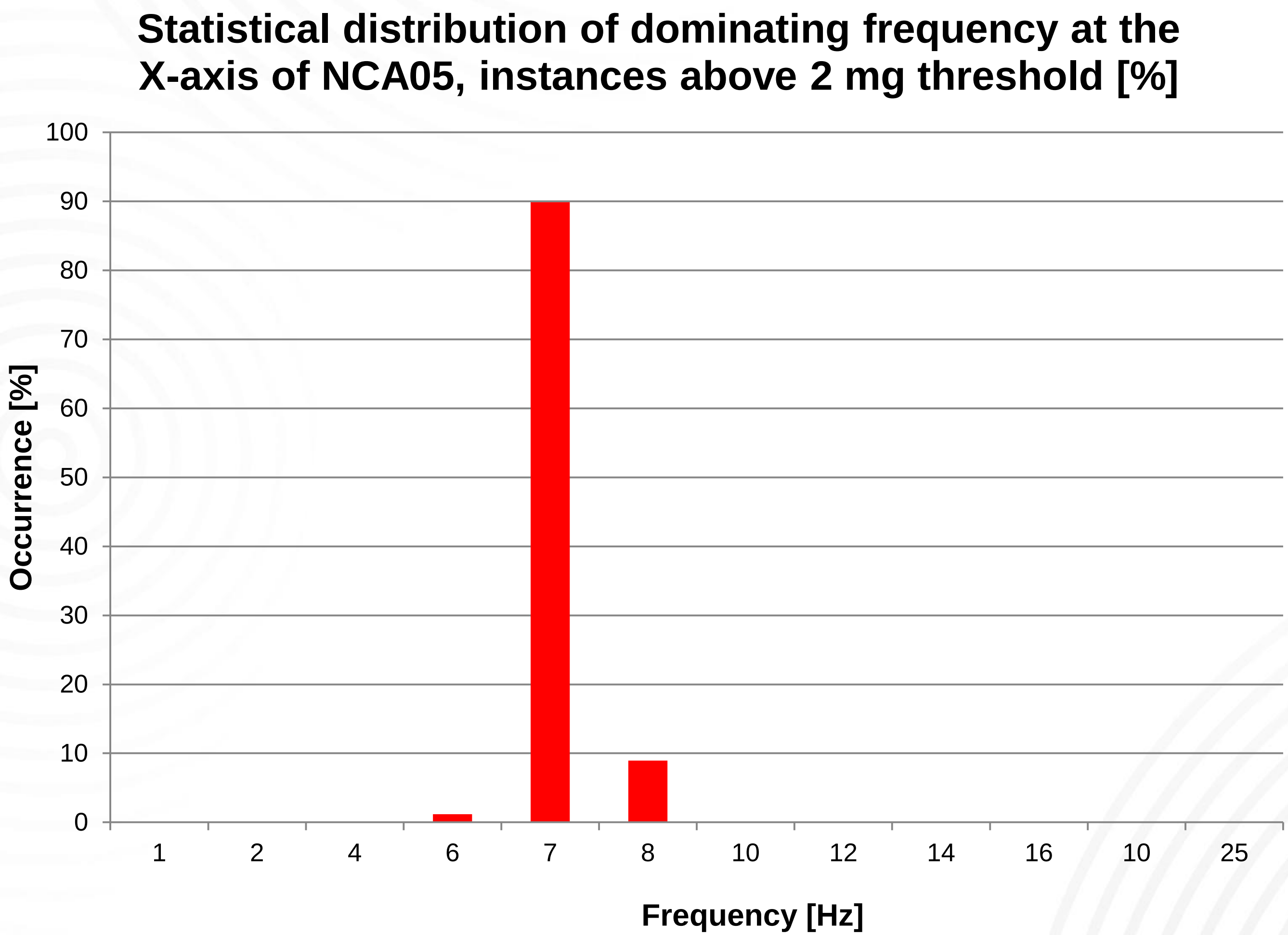
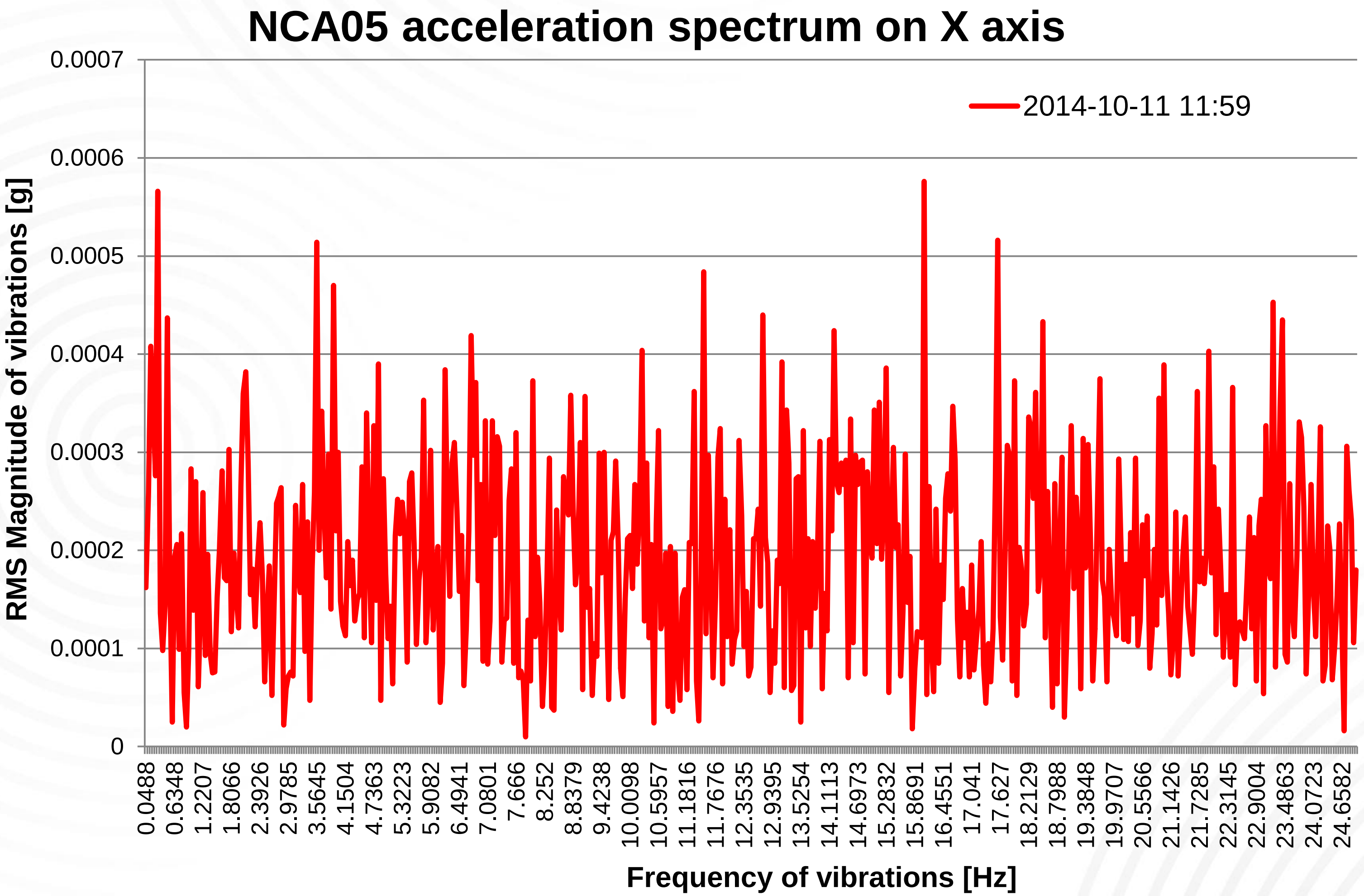
NCA05: Litus Lux Frequency Statistics



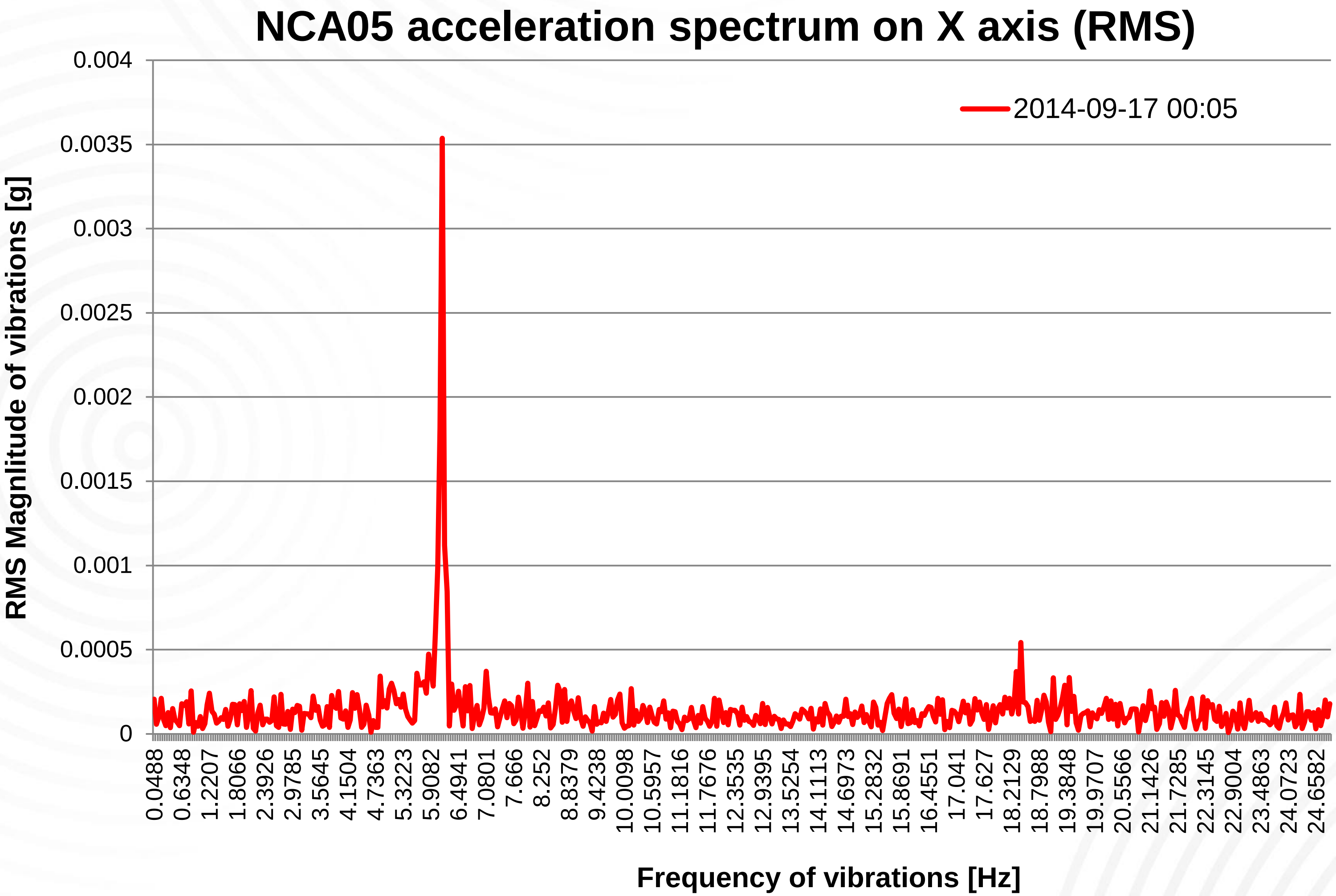
In nearly 2 months the dominant frequency was rarely detected outside typical bins

NCA05: Litus Lux Acceleration Spectrum



Frequency content of FFT analysis: **noise** (light air, southwest 1.2 m/s, gusts 1.8 m/s, -1.2°C)

NCA05: Litus Lux Acceleration Spectrum



Frequency: **6.1523 Hz** (fresh southwest breeze 9.2 m/s, gusts 13.2 m/s, 6.1°C)

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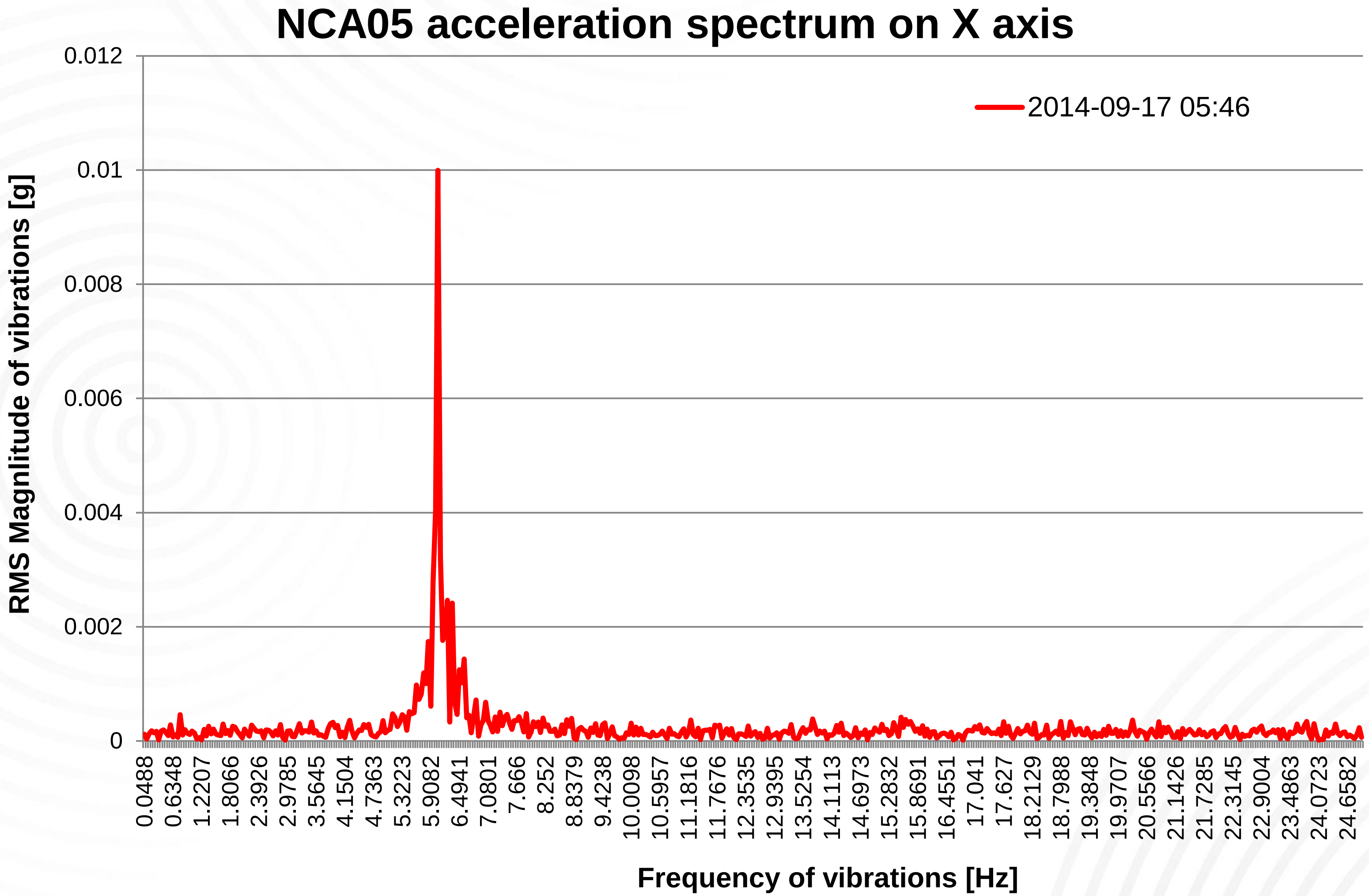
NCA05: Litus Lux Acceleration Spectrum



Frequency: **6.0547 Hz** (strong west-southwest breeze 11.5 m/s, gusts 15.9 m/s, 1.4°C)

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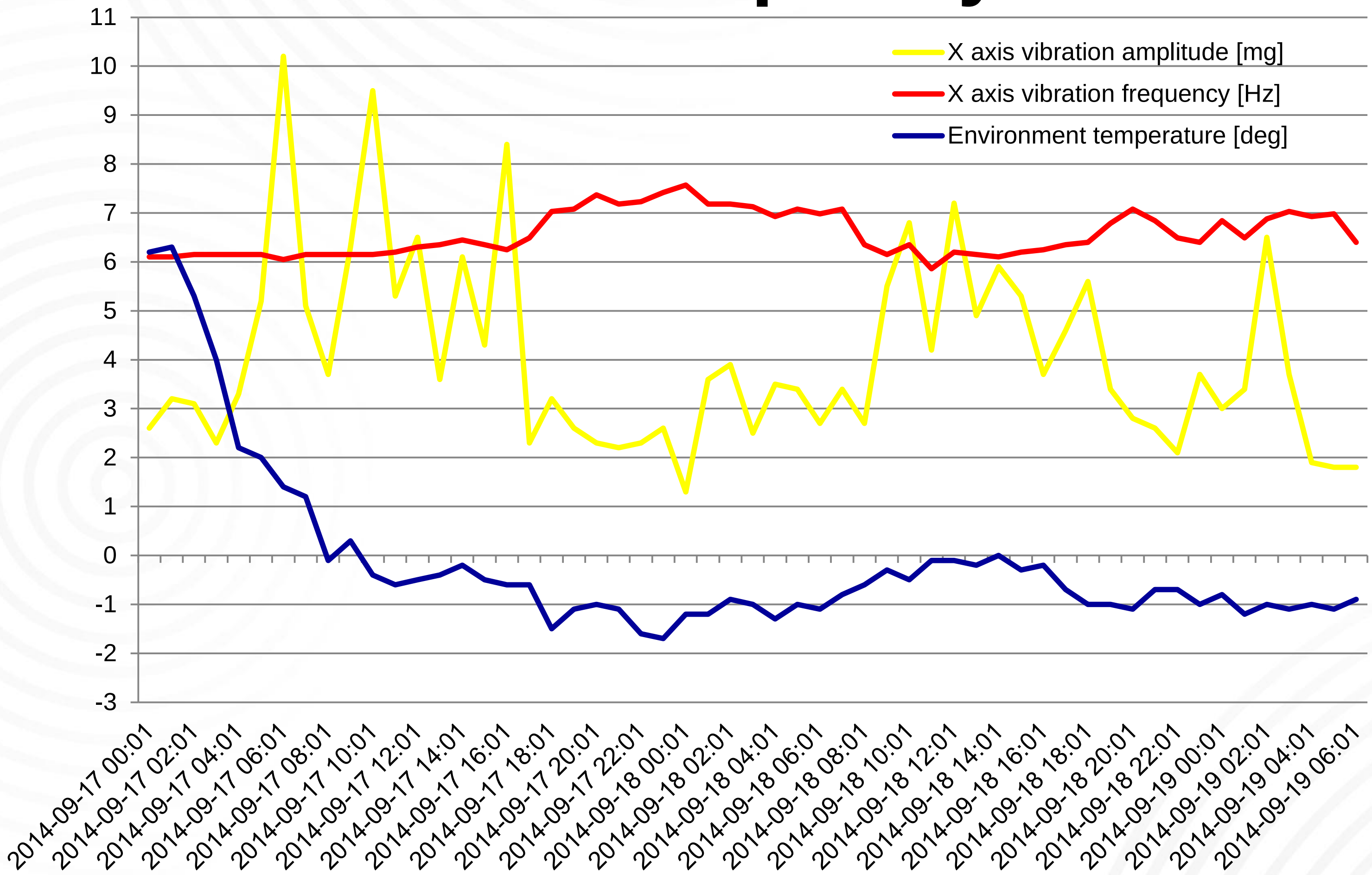
NCA05: Natural Frequency Drift in Cold



While typical results for NCA05 natural frequency analysis averaged around **6.15 Hz** at positive temperatures, it increased to **6.69 Hz** in above case and even **7.4 Hz below -10°C**

User Interface in Web Browser (PDA)

195.50.202.195

Kystverket-Cyber TeViNSA™ LSC AtoN Telematics Server 2.11

Site Name	Last Session	Voltage [V]	Heel Angle [deg]	Position	Script	Vibration X | Y | Z
NCA01	2014-11-06 10:53:29	12.95	3.0	On-site | T	Accel_Meas_Custom (20:4)	17 | 8 | 1
NCA02	2014-11-06 10:51:46	12.54	1.9	On-site | T	Accel_Meas_Custom (20:4)	4 | 5 | 1
NCA03	2014-11-06 10:51:49	14.15	0.3	On-site | T	Accel_Meas_Custom (20:4)	3 | 3 | 2
NCA04	2014-11-06 10:54:11	14.21	1.4	On-site | T	Accel_Meas_Custom (20:4)	0 | 1 | 1
NCA05	2014-11-06 09:59:16	12.72	1.3	On-site | T	Accel_Meas_Custom (20:119)	0 | 2 | 1

Page refresh time: 06.11.2014 at 10:55:16 UTC+1
Server started at: 22.10.2014 at 14:34:10

Server logfile Alarms logfile Heel angle and temperature logfile Last position of all AtoNs

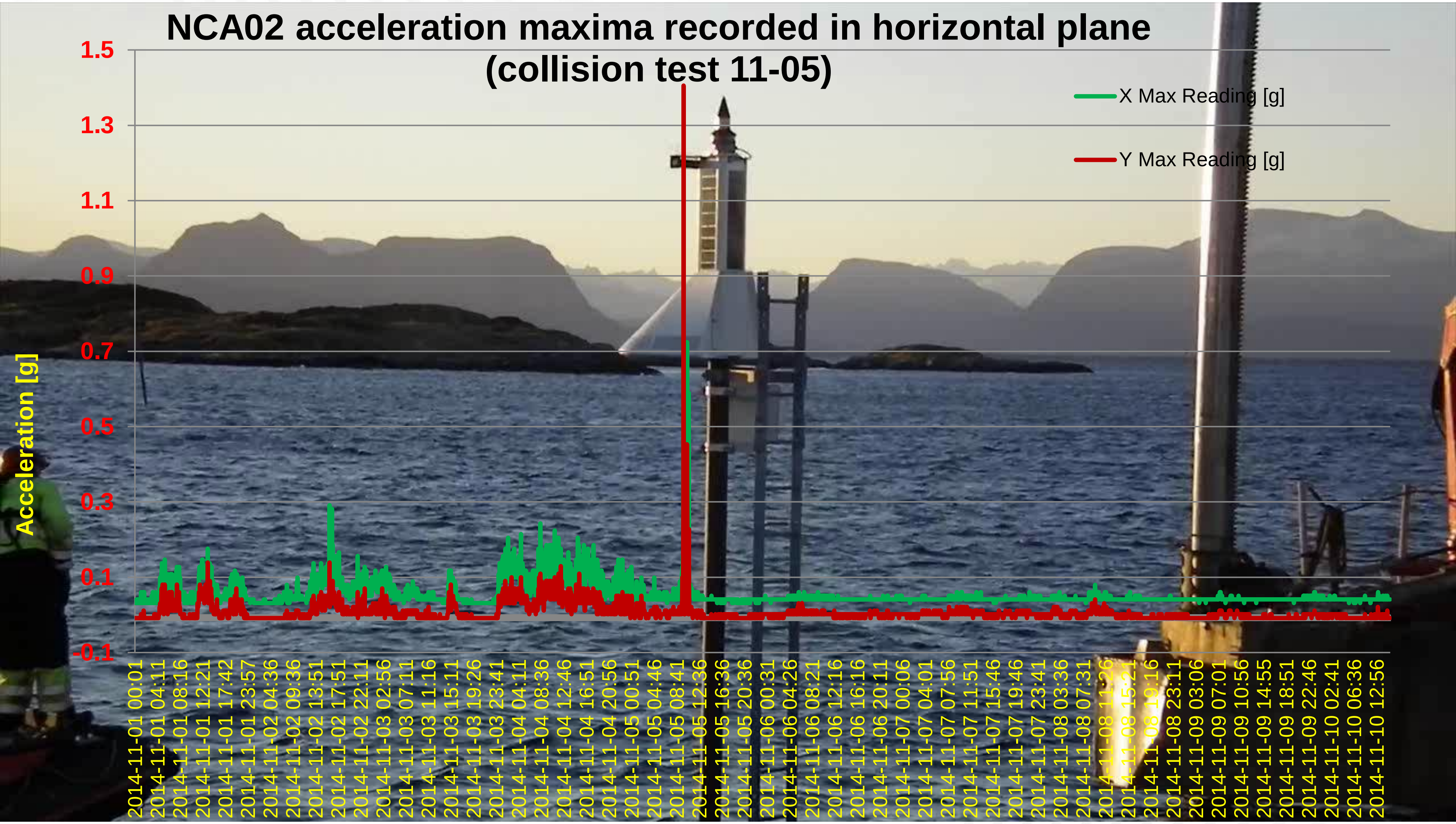
TLSC setup

Measurement Results, September/October

AtoN ID	AtoN Type	**Natural Frequency, X-axis [Hz]**	**Natural Frequency, Y-axis [Hz]**	**Peak Vibration Magnitude, X-axis [g]**	**Peak Vibration Magnitude, Y-axis [g]**	**Peak Acceleration, X-axis [g]**	**Peak Acceleration, Y-axis [g]**	**Maximum Inclination Angle Difference [°]**
NCA01	Dirigens Lux, 100 kg	**0.68**	**0.68**	0.141	0.119	0.423	0.324	1.92
NCA02	Dirigens Mini, 60 kg	**1.66**	**1.51**	0.095	0.750	1.061	1.395	1.88
NCA03	Original HIB, 500 kg	**0.59**	**0.59**	0.094	0.095	0.221	0.266	2.33
NCA04	Standard composite lighthouse, 1500 kg	**5.96**	**5.18**	0.097	0.147	0.453	0.488	0.84
NCA05	Litus Lux composite lighthouse, 500 kg	**6.15**	**5.86**	0.016	0.030	0.129	0.198	0.24

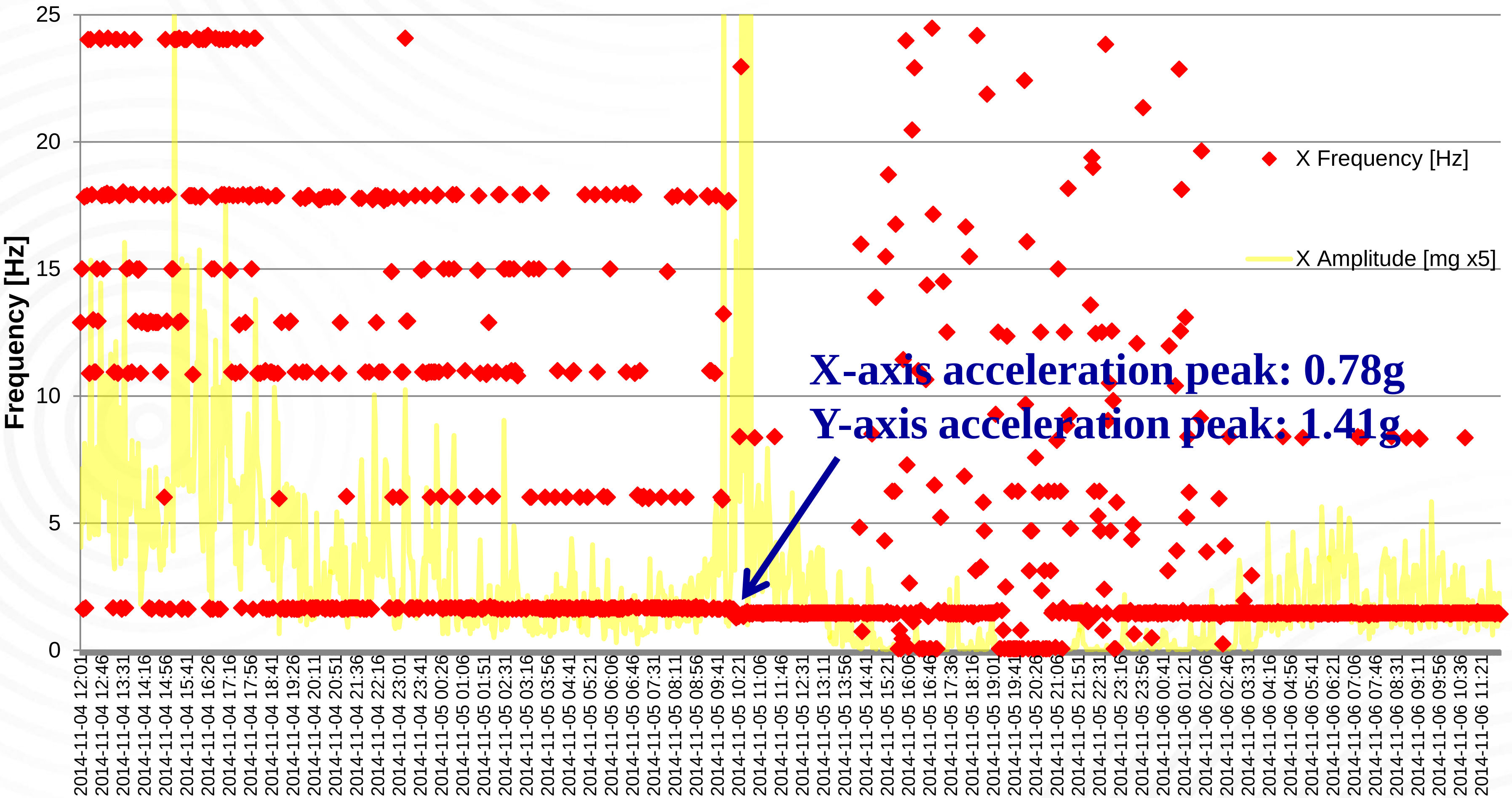
All types of fixed AtoN subject to SHM testing by TelFiCon™ units provided meaningful data

Collision Test on NCA02 on 2014-11-05



NCA02 AtoN platform acceleration and vibration magnitude peaks were recorded at 09:51

NCA02 Collision Test Results of 2014-11-05



Vibration profile of the NCA02 AtoN platform was changed permanently by the collision: **the X natural frequency shifted from 1.66 Hz to 1.46 Hz**, higher frequency components changed

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Conclusions

- Preliminary results of deployment of AtoN telematics controllers TelFiCon™ on the selected fixed AtoNs of the Norwegian Coastal Administration for SHM are useful

Application of fixed AtoN Structural Health Monitoring as described **increases navigational safety and optimizes corrective maintenance costs** by comprehensive watch:

- platform **inclination angles** (two alarm thresholds)
- horizontal and vertical **acceleration vector magnitudes**
- **amplitudes** of dominant components of vibration spectra (two thresholds) with immediate and detailed FFT analysis
- **frequency** of the dominant spectral component
- **collision events** detected even at TelFiCon™ standby

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Additional Information

Information on this AtoN Structural Health Monitoring project and associated technology can be requested from:

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