Project Title: Grayloc looseness monitoring using piezo transducers

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Problem Statement

- Grayloc connector seals are widely used in various industries and applications.
- Loosening of Graylocs directly results in preload decrease and initiates mechanical failure and leakage.
- We want to accurately predict the level of tightness of the grayloc seals.

Brief Literature Review

- Multiple methods of bolt looseness monitoring of regular flanges have been proposed by researchers.
- Traditional methods include the strain gauge-based methods, vibration-based methods, ultrasonic-based methods, and impedance-based methods.
- With the rapid development of smart materials and intelligent components, various methods embedded these components for flange looseness monitoring.

Experimental Setup and Collection of Data

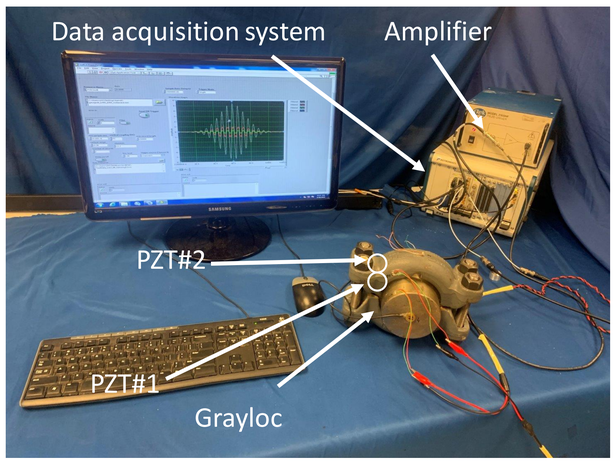
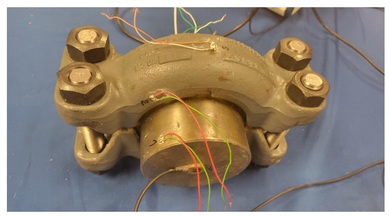


Fig 1: experimental setup



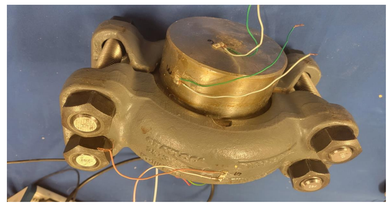


Fig 2: Grayloc with attached PZT transducers

- Lead zirconate titanate (PZT) are used as transducers and sensors to produce and receive stress waves.
- With the increase of the torque, the real contact area between the clamp and the pipe increases correspondingly: The energy transmitted by the stress wave along the grayloc increases with its tightness.
- Coda waves, which are the back-scattering waves that carry useful information about the structure that they propagated on, is used to analyze the grayloc's tightness level.

Method(s)

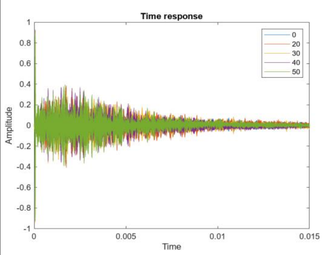


Fig 3: Time series response

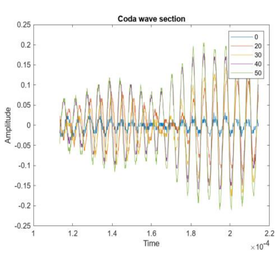


Fig 4: Coda wave response

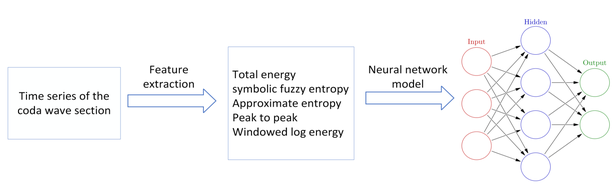


Fig 5: Flowchart of the proposed method

- A Gaussian impulse signal with 176kHz central frequency and 10MHz sampling rate was used to excite the PZT1 and measure the response at PZT2.
- The test consists of taking the response signal of 0 – 20 – 30 – 40 - 50 ft lbs.
- The data set consist of 1200 measurements, done in 33 independent subsets.
- The entropy is an effective nonlinear signal analysis technique that measures the complexity and the disorder of a given time series.

Results, Analysis and Discussion

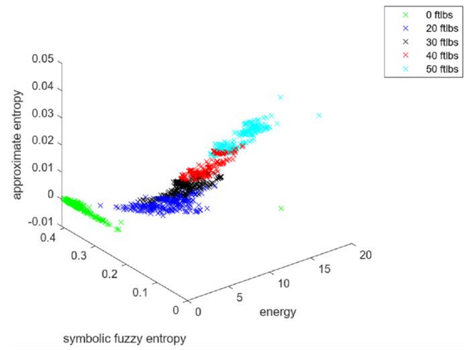


Fig 6: 3D plot of three features

	SVM		Neural network	
Features	Dependent	independent	Dependent	independent
MFCC	66.31 %	56 %	77.89 %	58.4 %
Energy + entropy	88.07 %	81.6 %	93.68 %	94.8 %
Proposed features	95.08 %	91.6 %	98.24 %	97.2 %

Table1: accuracy of various methods

- The data set was divided into training, testing and independent verification sets.
- The suggested features are correlated to the tightness of the grayloc, which explains the high accuracy.
- The maximum error of the testing sets was 10 ft lbs, which shows that this model has good robustness.

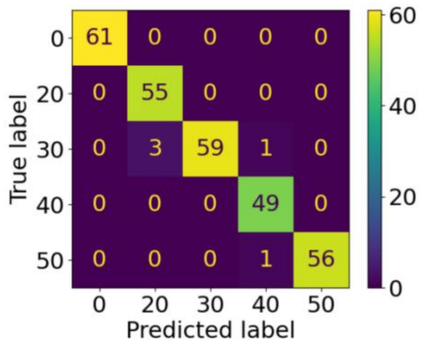


Fig 7: Confusion matrix of the dependent tests using neural network

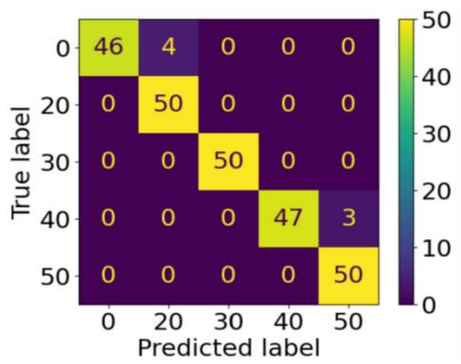


Fig 8: Confusion matrix of the independent tests using neural network

Conclusion

- We proposed a new method to monitor the looseness of graylocs using Lead zirconate titanate transducers.
- The coda waves carry useful information about the structure that they propagated on.
- This method, since it is based on the energy and entropy of the propagated stress wave, present an effective way to accurately detect the torque level of the grayloc.
- Future experiments will investigate the feasibility of this method underwater, as well as the monitoring of each bolt separately.

Acknowledgements

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