ASSESSMENT OF PROPELLER CAVITATION INCEPTION SPEED BASED ON ONBOARD VIBRATION AND UNDERWATER ACOUSTIC DATA

Kamal Kesour *[1], **Paul Camerin** †[1], **Jean-Christophe Marquis Gauthier** ‡[1], **Cédric Gervaise** ♦[2]
[1]Innovation maritime, Rimouski, Québec, Canada.
[2]SenseaFR, Grenoble, France.

1 Introduction

The underwater radiated noise (URN) level made by commercial shipping has been steadily rising in recent decades, reaching a point where it is recognized as a significant environmental issue. This increase in noise is related to the growing number and larger sizes of commercial vessels. Adverse effects of underwater noise have been observed in various species, including mammals, fish, and invertebrates. The URN emitted by a ship primarily consists of three types of noise: machinery noise, propeller noise, and hydrodynamic noise. At low speeds, machinery noise is the dominant factor, while at high speeds propeller noise is the main source of noise, particularly when propeller cavitation becomes more pronounced. Estimating the cavitation inception speed (CIS) enables an optimum trade-off between maximizing speed and minimizing noise. Consequently, it is crucial to identify the CIS in order to reduce propeller noise and mitigate its impact on the surrounding marine life.

The propeller's rotation creates a localized under-pressure, forming water vapor bubbles on the hub, blade surfaces, or between the hull and blades. As this depression is localized, the pressure within the fluid is quickly rebalanced, causing the implosion of the bubbles. The implosion of cavities causes damage to the propeller surface in the form of pitting, which can be negligible or considerably deep and lead to rupture. Cavitation also degrades propulsion performance due to water layer delamination. Radiated propeller cavitation noise is a broadband noise whose intensity depends on ship speed, propeller technology, wake and hull hydrodynamic profile.

This paper uses vibrational data in order to detect the occurrence of propeller cavitation as well as to estimate the CIS. The onboard vibration analysis results are validated against underwater acoustic data provided by the Marine Acoustic Research Station (MARS).

2 Methodology

There are several techniques for detecting the presence of propeller cavitation, using sensors installed either on board the ship or externally. Sensors used outside the ship consist mainly of hydrophones. On board ships, various techniques have been developed to characterize the occurrence of cavitation. A distinction can be made between intrusive (e.g. borescope, high-speed camera, pressure sensor) and non-intrusive methods. The latter class is particularly interesting, as it ensures minimal installation costs and preserves the integrity of the ship's hull. The aforementioned approach uses vibration sensors to assess the presence of propeller cavitation. The disadvantage of this type of method is that it requires more sophisticated algorithms to detect propeller cavitation, due to the presence of several potential sources of vibration (engines, pumps, gears, etc.).

By analyzing the vibration and underwater acoustic data generated by the propeller, unique frequency patterns generated by the propeller's cavitation can be identified. In this context, Detection of Envelope Modulation On Noise (DEMON) [1] and Integrated Cyclic Modulation Coherence (ICMC) [2] algorithms are employed. To fully automatize the detection of cavitation, the Fast kurtogram [3] is used to identify the frequency band of demodulation (resp. integration) for DEMON (resp. ICMC). The frequency band with the highest spectral kurtosis is selected from the fast kurtogram.

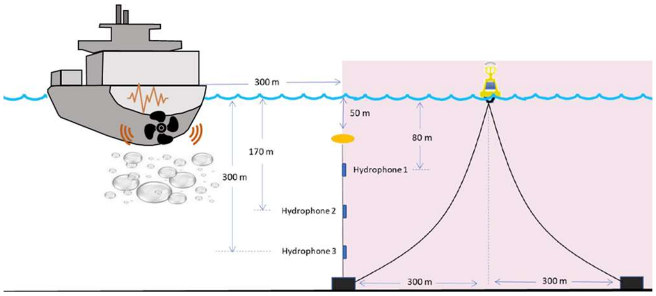

Figure 1: Passage of a vessel through the MARS Station.

The Cavitation generates high-frequency, broadband noise which is modulated by the shaft rotation and propeller blade passage frequencies. The DEMON method involves applying a band-pass filter to extract the modulated signal. The accuracy of the DEMON method is closely linked to the choice of the frequency band of the band-pass filter. Next, the envelope of the modulated signal is obtained by keeping only the low-frequency component (i.e. envelop). Finally, the DEMON spectrum is computed by the fast Fourier transform (FFT) of the envelope.

The ICMC method is based on the principle of cyclostationarity, which provides a rigorous basis for tackling detection problems. First, power spectra are calculated from the measured signal. Then, for each frequency, the power spectrum is calculated over the time axis, leading to a cyclic modulation spectral matrix as a function of frequency and cyclic modulation frequency α. The latter matrix is normalized to form the cyclic modulation coherence (CMC) by dividing it by the frequency spectrum at $\alpha = 0$. Finally, the ICMC is obtained by integrating over the frequency band identified by the fast kurtogram.

---

* kkesour@imar.ca
† pcamerin@imar.ca
‡ jcgmarquis@imar.ca
♦ cedric.gervaise@senseafr.com

Finally, an analysis of the frequency content of the DEMON or ICMC spectrum of the modulated signal shows whether or not the propeller is in cavitation. The CIS is identified by tracking the maximal amplitude of the propeller shaft rate and its harmonics at different speeds.

3 Results

In this work, the research vessel Coriolis II was instrumented by using accelerometers (PCB 352C33) above the propeller and tachometers to track propeller shaft rotation. The Coriolis II is a 50 m long ship constructed in 1990, equipped with 4-bladed twin screws. Aiming to estimate the CIS, the ship passed through the Marine Acoustic Research Station (MARS) at various speeds (between 2 and 12 knots). Figure 1 shows an antenna of the MARS station composed of three-hydrophone arrays.

3.1 Cavitation detection

Figure 2 shows an example of the obtained ICMC spectrum at a speed of 12 knots. The Shaft rate and its harmonics are clearly identified in the figure which indicates that the propeller was in cavitation at this specific speed.

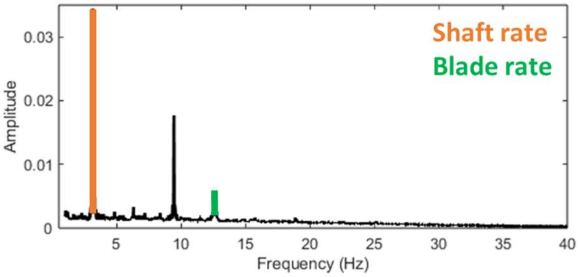

Figure 2: ICMC spectrum using onboard vibration data.

3.2 CIS estimation

In order to estimate the CIS, the maximal amplitude of the shaft rate and its harmonics were tracked over 36 passages of the Coriolis II. Figure 3 shows the results obtained by the ICMC method from vibration data recorded by a sensor placed above the starboard propeller. It's observed that CIS can be estimated around a speed of 8 knots defined by the intersection between the two slopes. The same CIS estimation is obtained by applying the DEMON algorithm to the underwater acoustic data as shown in Figure 4. This result demonstrates that the CIS estimation from onboard data can be a reliable tool, according to the underwater noise analysis.

4 Conclusion

This paper examined the use of onboard vibration data to estimate the CIS and detect its occurrences. In this context, two algorithms were developed and employed to indicate the occurrence of cavitation, namely: the DEMON and ICMC algorithms. The CIS was estimated by tracking the maximal amplitude of the propeller shaft rate and its harmonics at different speeds. The results using on onboard vibration data were validated against the underwater acoustic ones. The results show that the two algorithms of the estimation of the CIS are fairly accurate and reliable. However, more data are required to fully validate the developed methodology. Thereafter, the use of onboard vibration data has the potential to become a standard practice for detecting propeller cavitation, estimating the CIS and potentially reducing underwater noise pollution in the maritime industry.

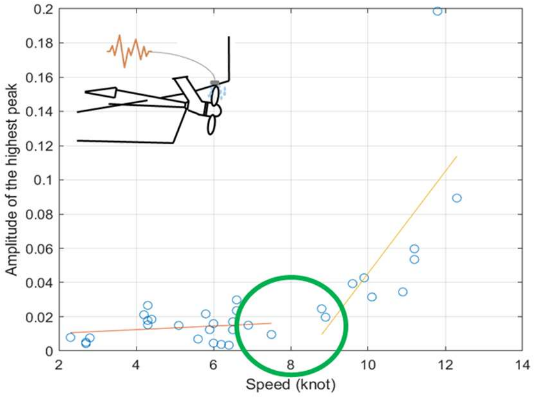

Figure 3: Maximal amplitude of the onboard vibration ICMC spectrum at different vessel speeds.

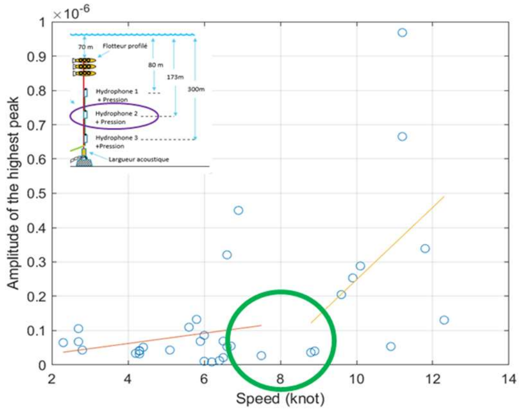

Figure 4: Maximal amplitude of the underwater acoustic DEMON spectrum at different vessel speeds.

Acknowledgments

The authors would like to thank Tranport Canada (TC) and the Ministère de l'Économie, de l'Innovation et de l'Énergie (MEIE) du Québec for their financial support. The authors would like to thank the Réseau Québec maritime (RQM) to have made the Coriolis II available for the measurements.

References

[1] Han, H. S., Lee, K. H., & Park, S. H. (2016). Evaluation of the cavitation inception speed of the ship propeller using acceleration on its adjacent structure. Journal of Mechanical Science and Technology, 30(12), 5423-5431.

[2] Antoni, J., & Hanson, D. (2012). Detection of surface ships from interception of cyclostationary signature with the cyclic modulation coherence. IEEE Journal of Oceanic Engineering, 37(3), 478-493.

[3] Antoni, J. (2007). Fast computation of the kurtogram for the detection of transient faults. Mechanical Systems and Signal Processing, 21(1), 108-124.