CAV2021
11th International Symposium on Cavitation
May 10-13, 2021, Daejon, Korea

Underwater Noise Measurements with a Ship retrofitted with PressurePores™ Noise Mitigation Technology and using HyDrone™ System

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Abstract: This paper presents the sea trials results by measuring the underwater radiated noise (URN) levels of a research vessel retrofitted with the novel "PressurePores™" URN mitigation technology on her propellers to demonstrate the effectiveness of this technology in full-scale. Tip Vortex Cavitation (TVC) is one of the main contributors to a URN. So the strategic implementation of the PressurePores™ is aimed to reduce the TVC and subsequent URN of ship propellers. During the sea-trials, the URN levels were measured when the vessel's propellers were in the unmodified (without PressurePores) and modified (with PressurePores) conditions, including comprehensive cavitation observations using a high-speed camera to assess PressurePores™ technology. The trial results showed this innovative technology could mitigate the TVC and resulting URN signature by 10dB. Also, in this measurement campaign, a novel URN measurement method using an aerial drone with a miniature hydrophone called the "HyDrone™" system was tried successfully. HyDrone™ can be a flexible and practical alternative URN measurement technique to the conventional tethered-based method to improve the undesirable background noise corrections.

Keywords: PressurePores™ Noise Mitigation Technology; Full-scale Underwater Radiated Noise (URN); Cavitation Noise Mitigation; HyDrone™ URN Measurement System.

1. Introduction

Underwater radiated noise (URN) caused by propeller cavitation is one of the most adverse environmental by-products of commercial shipping [1]. It can be as loud, deafening and disorientating marine fauna, disrupting their communication signals, making mating difficult and leaving them vulnerable to predators and local extinction. Unlike other forms of marine pollution, there is no legislation yet in place to prevent this type of environmental damage; although the problem was recognised by the United Nations and other international (e.g., IMO, EU, some Class Societies) and national authorities who called for more research on the impact of URN and for countries to mitigate ocean noise where possible.

One of the major contributions to the propeller induced URN is the tip vortex cavitation (TVC). There are different methods to control and mitigate the TVC that can be classified as active and passive methods [2]. Recently, a novel passive method, called PressurePores™ technology, capable of substantially reducing URN, has been developed and patented by the University of Strathclyde and Oscar Propulsion [3,4]. PressurePores™ involves applying a strategically located number of small holes (pores) at the tip region of the propeller blades to mitigate the TVC and subsequent URN. This technology was developed based on comprehensive numerical and experimental investigations using CFD methods, cavitation tunnel tests and towing tank experiments to reduce the URN with a minimum compromise to the propeller efficiency. The effectiveness of the technology was demonstrated successfully at a model scale (1:3.5) by using the propeller of Newcastle University's research vessel, "The Princess Royal", as the benchmark propeller.

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These investigations reported a significant reduction in the URN levels (up to 17dB) with approximately 2% reduction in the propeller efficiency, e.g. [3]

Within the above framework, the next stage development programme of the PressurePores™ technology was to demonstrate its effectiveness in full-scale by applying this technology to The Princess Royal's propellers. This paper, therefore, presents and discusses the results of the full-sale application of PressurePores™, cavitation observations made, and URN measured based on the sea-trials conducted with The Princess Royal in the North Sea during August 2020. The paper also introduces a novel URN measurement system, "HyDrone™", using an aerial and splash drone with a compact hydrophone, as an alternative and practical measurement system to the conventional tethered-based system with an array of hydrophones, which was used to assess the mitigation performance of PressurePores™.

2. Underwater Radiated Noise Measurements Set-up

The URN measurements and cavitation observations were conducted [5] in the NE of England (off Blyth coast with an average water depth of 70m) with Newcastle University's research catamaran, "The Princess Royal" [6], fitted with two fixed pitch and 5 blade propellers based on the following configurations: a) Unmodified propellers with no pores drilled; b) Modified propellers with lesser number of pores drilled at the tip region of each blade; c) Modified propellers with an increased number of pores drilled. The corresponding propeller conditions are shown in Figure 1.

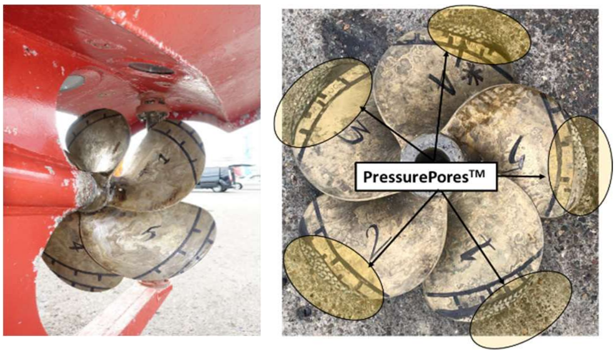

Figure 1. Propeller configurations tested: Unmodified port side propeller fitted to the research vessel – Suction side view (Left); Modified starboard propeller with PressurePores™ applied at the blade tip regions - Suction side view (Right)

Figure 2. URN trials set up: Research vessel "The Princess Royal" passing by at full speed (Left); Support vessel deploying the hydrophone system with The Princess Royal passing at 100m CPA on the background (Right)

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The URN levels of the target vessel (The Princess Royal) for each of the above configurations were measured using a conventional hydrophone system (RTSys) with three sensors tethered and deployed from a support vessel which was anchored during the measurements in compliance with the ANSI and ISO standards [6, 7]. The RTSys hydrophone system had its three sensors located at 10m, 25m and 45m depth. The URN levels were recorded as the target vessel passed by the support vessel at a range of engine speeds. The speed range included 600, 900, 1200, 1500, 1750 and 2000 rpm, which covered an almost entire power-speed range of the vessel. The gear ratio between the engine and propeller of the target vessel is 1:1.75. Figure 2 shows the target vessel's pictures (in blue) and support vessel (in white) when the trials were underway.

3. Cavitation Observations Set-up

During the trials, the observations of the cavitation inception and development on the propellers were essential. Hence, a high-speed video (HSV) camera (PHOTRON Fastcam Mini UX; 1.3 megapixels; 4000fps) supported by a continuous powerful light source was used for recording. By using this system, the views of the starboard (STB) propeller were recorded through the two portholes of the vessel with plexiglass windows situated above the propeller. The view of the portholes, set up of the HSV camera and light source at the aft end region of the STB engine room is shown in Figure 3.

Figure 3. Starboard (STB) propeller observation windows (portholes) used for HSV recording (Left). HSV Camera and light source set-up at the aft end region of the STB engine room (Right).

4. Underwater Radiated Noise (URN) Measurement Results

Data acquisition for each run was started when the target vessel team confirmed to the support measurement team via radio communication and confirmed via post-processing of the GPS position of the vessel. The data for each run was analysed in compliance with the ANSI and ISO standards [7,9]. An overall analysis of the results for the two configurations of the PressurePores™ (i.e. two different numbers of pores) indicated that the configuration with the increased number of pores displayed clear benefits of the PressurePores™ for the URN mitigation, while the lesser number of pores configuration did not show any benefit. Hence the results with the increased number PressurePores™ are presented here. Figure 4 shows the comparative net URN (or Sound Pressure Level (SPL)) spectra of the unmodified (no pores) and modified (with pores) propellers at 900 rpm and 1200 rpm speed conditions. Analysis results were focused on the 10 to 1000 Hz frequency band as this is the critical range for marine mammals. The CPA (Closest Point of Approach) was 100m during the measurements.

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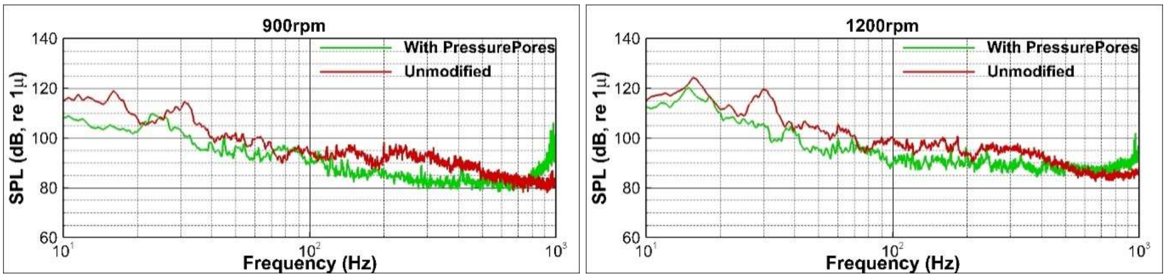

Figure 4. Comparisons of unmodified and modified propellers URN level spectra at 900 RPM (Left) and 1200 RPM (Right).

As shown in Figure 4, a 10 dB noise level reduction was achieved with PressurePores™ around 300Hz at 900 rpm speed (left) and around 100Hz at 1200 rpm speed (right). The URN mitigation was reduced to about 5-8 dB between 250Hz and 400Hz, while they crossed over at about 600Hz. As presented in the next section, the cavitation type observed was mainly the tip vortex cavitation (TVC) with increasing density until 1500 rpm, while at and after 1500rpm, sheet cavitation became dominant. In the higher engine speed range, PressurePores™ still reduced the URN levels at about 5dB between 200 and 300Hz. In contrast, the levels of the URN of the unmodified and modified propeller were essentially the same, between 400Hz and 1000Hz. At full power (i.e., 2000rpm), there was a small benefit at a range from 200 to 300Hz, while a 5dB increase was noticed with the modified propeller over a range from 500Hz to 1000 Hz. These findings indicated that PressurePores™ was effective to reduce the URN levels where the TVC was dominant.

Although the benefit of PressurePores™ diminished at the higher engine speed range, where the sheet cavitation was dominant, in this high-speed range, interestingly, the URN amplitudes at the 1st Blade Passing Frequency (BPF) peaks were reduced up to 6dB. In comparison, at the second BPF peaks, the reduction was less (2 dB) or non-existent, as shown in Figure 5 for engine speeds 1500, 1750 and 2000 rpm.

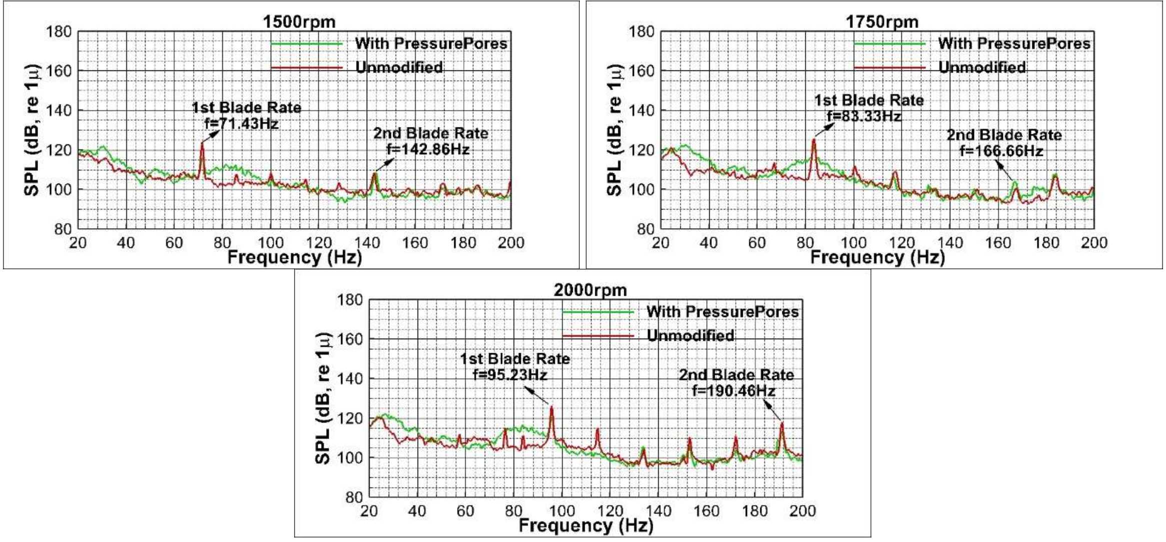

Figure 5. Comparisons of unmodified and modified propellers URN level spectra at 1500, 1750 and 2000 rpm.

While the PressurePores™ displayed clear benefits in the low to medium range of engine speeds (up to 1500 rpm), the measured URN level with the PressurePores™ displayed local peaks at 1 kHz and 2kHz in the same range. Audio recordings both on and off-board suggested a whistling (or singing) phenomenon.

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The unmodified propeller, which did not include anti-singing blade edges, also showed a 1kHz component peak. It was not clear if this problem was of a hydrodynamic nature or, being incipient on the unmodified blades, was due to the blade resonant frequencies, which affected singing having been altered such that the hydrodynamic forces excited the blade dynamics. It was also possible that the local edges of the pores caused such whistling, but no such correlation has been established. In addition, the tone at about 1 kHz could also be structural and could be due shaft bearing requiring further investigations, which are underway.

5. Underwater Radiated Noise (URN) Measurement Results

A wide range of views during the cavitation inception tests was recorded as well as the full range of views in the URN measurement tests. As typically shown in Figure 6, while the unmodified propeller displayed solid TVC development, the modified propellers with two different numbers of pores displayed hardly any TVC, although there was local inception of cavitation around each pore.

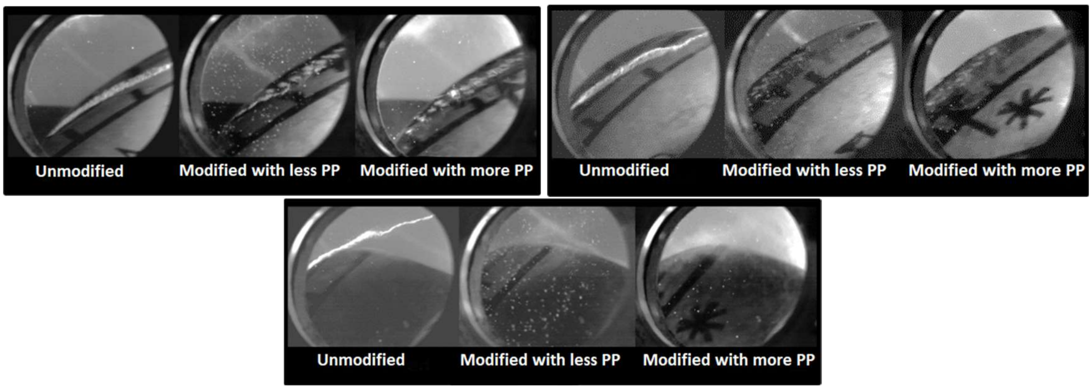

Figure 6. Propeller cavitation views at 800rpm (Top left: Leading edge view Top right: Mid-chord view Bottom: Trailing edge view)

The above trend, which indicated reduced volume and intensity of the TVC, was kept until the sheet cavitation became dominant; as such, while the unmodified propeller experienced more intensified TVC with increasing shaft speeds, the modified propeller displayed gradually developing TVC with a much-reduced rate and in diffused nature, as shown in Figure 7, e.g., at 900 rpm. Once the sheet cavitation developed, the differences in the cavitation patterns of the unmodified and modified propeller were not so obvious, although the TVC trajectories downstream for the modified propeller were relatively weaker. These trends clearly supported the reduced URN levels measured with the modified propellers, especially at the speed range where the TVC is dominant in diffuse nature and with reduced cavity volumes.

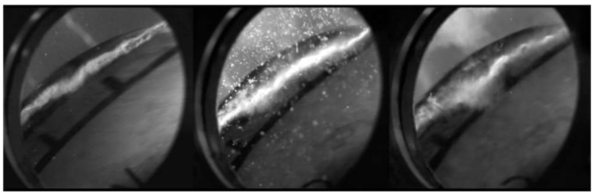

Figure 7. Comparative cavitation views about tip mid-chord region: Unmodified propeller (Left); Modified Propeller with less number of PressurePores™ (Middle); Modified Propeller with increased number of PressurePores™ (Right).

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6. Underwater Radiated Noise Measurements (URN) with HyDrone™

As described in Section 2, the URN of the target vessel was measured by the traditional method of suspending an array of three sensors tethered and deployed from a support vessel. This method subjects the hydrophones to cross-flow velocities from the local current flow that can introduce extraneous noise, which may mask some ship noise sources. During the URN measurements, a pioneering alternative (HyDrone™) method was tested for measuring URN for limited cases. As shown in Figure 8, the HyDrone™ consisted of a floatable (splash) aerial drone from which a compact hydrophone (SoundTrap) was suspended on a 10m cable. The drone was landed on the water a short distance from the support boat, where it floated in the current, hence eliminating the extraneous noise from the current cross-flow. Figure 8 (on th left) compares the URN measurements at 900 rpm engine speed with the modified propellers from both systems for a sensor location 10m below the surface (i.e., HyDrone vs Sensor 1 (S1), the shallowest submerged hydrophone of the traditional system). This comparative data shows that the above about 800Hz, the two systems produced comparable URN levels. However, below 800Hz, the S1 hydrophone included considerable "background" noise to be corrected. Hence future measurements may be more accurately recorded using the HyDrone™ system.

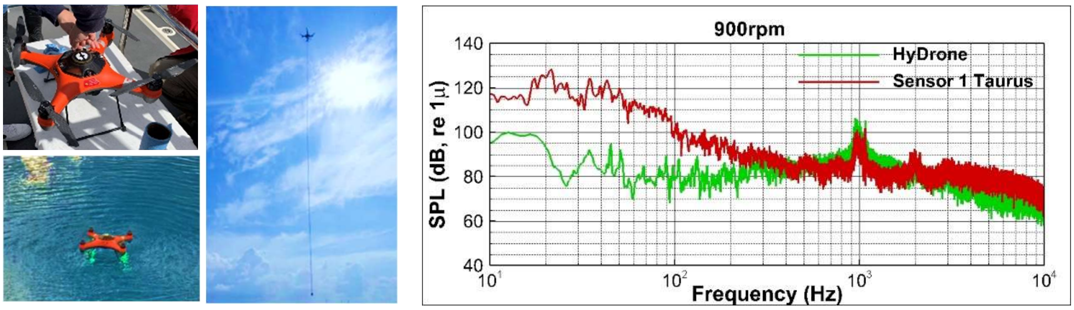

Figure 8. Comparison of URN spectra for 900 rpm speed from two different measurement systems: Drone-based hydrophone, "HyDrone™" and Tethered-based hydrophone, Sensor 1 at 10m (Right). Some pictures of HyDrone deployment (Left)

7. Conclusions

Full-scale URN measurements trials, including propeller cavitation observations, were conducted recently with research vessel The Princess Royal to assess the full-scale performance of the novel PressurePores™ noise mitigation technology retrofitted on her propellers. The trials involved the testing of the two pressure pores configurations together with that of the unmodified propeller arrangement, which served as the reference for comparison.

- These trials demonstrated strong evidence for the benefits of PressurePores™ technology by the reduced energy levels in the TVC dynamics and cavity volume reduction. This subsequently resulted in the mitigation of the URN levels up to a max 10 dB level up to 1 kHz for the low to medium speed range where the TVC was dominant.
- The URN level amplitudes at the 1st and 2nd BPFs in the higher speed range also displayed favourable reductions with the increased number of the pores.
- The measured URN data showed a singing-type phenomenon with both PressurePores™ configurations manifesting itself by the local spectral peaks at 1 kHz & 2KHz for slow to medium engine speeds requiring further investigations, least requiring an anti-singing edge application.

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- Novel "HyDrone™" URN measurement technology presented a flexible and practical alternative approach to the conventional tethered-based measurement system to improve the detrimental background noise correction.

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