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Acoustic Emission Monitoring of S.A. Agulhas II: Parametric Analysis and Correlation with Global Strain

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Abstract. . Ensuring the structural reliability of ships in demanding sea states requires monitoring approaches capable of detecting fatigue damage during operational conditions. This study investigates the application of Acoustic Emission through a full-scale monitoring campaign on board the Polar Supply and Research Vessel S. A. Agulhas II. Two sensor nodes were installed: one on the port side near an active fatigue crack and one on the starboard side in a previously repaired region, enabling a direct comparison under similar loading conditions. More than four million AE signals were recorded, with roughly 80% originating from the active-crack region. The analysis focuses on AE parametric features—amplitude, hit rate and cumulative counts—and their qualitative correlation with local strain gauge measurements. Differences between the two sensor locations are assessed to evaluate the sensitivity of AE parameters to local structural condition. The results offer practical insights on sensor placement, data handling and the integration of AE with complementary onboard measurements, contributing to the assessment of AE for in-service monitoring of ship structures.

Keywords: Acoustic emission, ship, fatigue, crack, strain

Introduction

The need for reliable in-service monitoring of fatigue induced damage in ship structures has driven increasing interest in structural health monitoring (SHM) techniques [1]. Fatigue cracks typically initiate at welded details and are difficult to detect during operational conditions, particularly at early stages [2,3]. In current practice, structural integrity is assessed through non-destructive testing (NDT) techniques performed during dry-docking, such as magnetic particle inspection (MPI), ultrasonic testing (UT) and visual inspections. These procedures can be time-consuming, physically demanding and costly, and more importantly, they do not capture damage evolution between inspection intervals [4]limiting the ability to quantify crack growth rates, update damage models or anticipate critical thresholds. Continuous monitoring techniques can provide real-time information on damage activity, which can be used as input for damage models and support the estimation of fatigue life. SHM systems aim to address this limitation by measuring changes in structural response and relating them to damage progression, thereby enabling ongoing integrity assessment and supporting condition-based and predictive maintenance strategies. Among SHM techniques, Acoustic Emission (AE)

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monitoring can detect active crack growth in real time by capturing stress waves generated by damage mechanisms [5–7].
At the laboratory scale, AE has been extensively validated for detecting fatigue crack growth in both metallic and composite specimens [8–10]. These studies demonstrated that parametric AE features including cumulative counts, amplitude and energy, correlate with different stages of crack growth. AE has also been applied to large-scale and in-service structures. In steel bridge monitoring, field measurements have shown that AE can detect and locate fatigue cracks under real traffic loading conditions [11]. In laboratory environments, full-scale tests on mooring chains demonstrated the capability of AE to detect corrosion-fatigue and fatigue-only crack-related emissions [12,13], while AE monitoring of large-scale roller bearings, typical of offshore crane applications, has shown that waveform based clustering of AE waveforms can identify naturally developed damage under fatigue loading [14]. Despite the growing applications in other areas, the application of AE monitoring to full-scale ship structures has so far remained limited and published in-service studies on operating vessels are scarce [1].

This study aims to evaluate the feasibility of an AE monitoring campaign on a full-scale vessel under operational conditions. Feasibility is here assessed in terms of the ability to reliably measure AE signals under operational noise conditions, whether AE activity can distinguish between repaired and unrepaired locations as be correlated to crack growth, and the correlation between AE activity and structural strain parameters under operational loading. To this end, a monitoring campaign was conducted during a 10-day voyage of the Polar Supply and Research vessel S.A. Agulhas II, owned by the Department of Forestry, Fisheries and the Environment of South Africa and operated by African Marine Solutions (AMSOL). Two AE sensor nodes were installed symmetrically on the side shell at the upper deck level: one on the port side near a visually identified crack, and one on the starboard side in a region without known active damage. This configuration enabled a direct comparison of AE between an active crack and a nominally inactive structural region subjected to comparable loading conditions. The analysis focuses on parametric AE features. Alongside AE measurements, the vessel was instrumented with strain gauges, and operational and environmental data, including GPS and weather conditions, were available. This allows for a qualitative correlation between AE activity, structural loading and environmental conditions experienced during the voyage. The paper is structured as follows. Section 1 provides theoretical background on the AE monitoring approach. Section 2 and 3 describe the monitoring campaign and instrumentation respectively. Section 4 presents the results and discussion. Conclusions are drawn in Section 5.

1. Theoretical Background

In thin-walled steel structures such as ship hulls and decks, AE signals propagate as ultrasonic guided waves. These waves are multimodal and dispersive: multiple wave modes can propagate simultaneously, each with frequency-dependent velocities and characteristics [1,2]. The recorded AE signal P is therefore a superposition of wave modes that evolve as they travel through the structure and can be expressed using Equation (1).

$$P_j = \sum_{i=1}^{n} D_j W_i S + N \quad (1)$$

where D_i represents the transfer function of sensor j, W_i is the transfer function of the medium through which n total modes can co-exist and propagate, S is the source signal and N is the background noise component.

In this study, the AE propagation in the symmetrical structural regions of the ship on the port and starboard side can be observed in Fig. 1. Due to the comparable structural details and sensor positions on both port and starboard sides, the influence of stiffeners, welds and other structural elements (embedded in the term W) is assumed to be similar. Additionally, as the same sensor types are used in both locations, the sensor transfer function D is considered constant. Furthermore the choice of

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transducers and the coupling mechanism is made such that the fundamental antisymmetric *A0* mode is the dominant wave mode captured[3]. Under these considerations, the recorded AE responses at each location can be interpreted primarily in terms of difference in the crack-induced source, enabling a direct comparison between the active crack region and the previously repaired one. The influence of operational background noise *N* is addressed through the selection of sensors operating in a frequency range, where background noise levels are expected to be lowest.

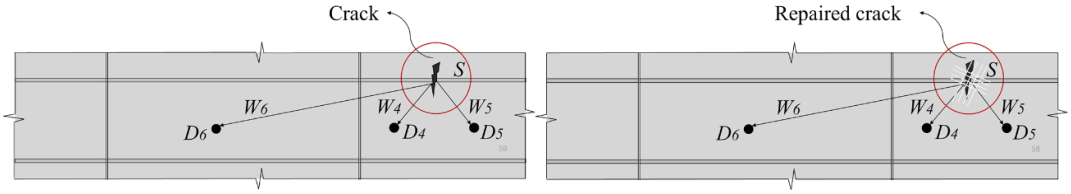


Fig. 1 Wave propagation in stiffened steel panels on Port (left) and Starboard (right) side of the ship.

The analysis focuses on comparing the AE activity between the monitored regions using parametric analysis [4,5], where discrete signal features are extracted from each detected hit. The parameters considered include peak amplitude, hit rate and cumulative hits, which serve as qualitative indicators of damage activity and allow for comparison between monitored locations and correlation with structural loading conditions.

2. Vessel and Monitoring Campaign

2.1 Vessel Description and Voyage

The monitoring campaign was conducted on board the Polar Supply and Research Vessel *S.A. Agulhas II* (see Fig. 2), operated by African Marine Solutions (AMSOL). The vessel features a reinforced, stiffened steel hull designed for operations in harsh environments, with a PC-5 ice rating. The principal dimensions of the vessel include an overall length of approximately 134.2 m, a beam of 21.7 m, and a draft of 7.65 m [6]. The data presented in this study was collected during the SEAmester VIII cruise, a 10-day round trip departing from and returning to Cape Town from the 17th to the 27th of June 2025. Throughout the voyage, the vessel encountered varying sea states, wind conditions and vessel speeds, resulting in fluctuating structural loading. Operational data, including vessel position and navigation parameters, were recorded onboard.



Fig. 2 S.A. Agulhas II [7].

2.2 Monitored Structural Regions

Two regions located on the side shell at upper deck level were selected for AE monitoring, chosen to enable a comparative assessment of AE activity under similar global loading conditions. The first region, on the port side, presented a visually identified fatigue crack at the time of installation. The second region, on the starboard side, corresponded to a previously repaired crack location, considered

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representative of a visually intact region. Both regions are located on the sheer strake at Deck 4 level, near the welded connection between the deck plating and the side shell structure as shown in Fig. 3. The sheer strake has a plate thickness of 10 mm, with bracket spacing of 1200 mm.

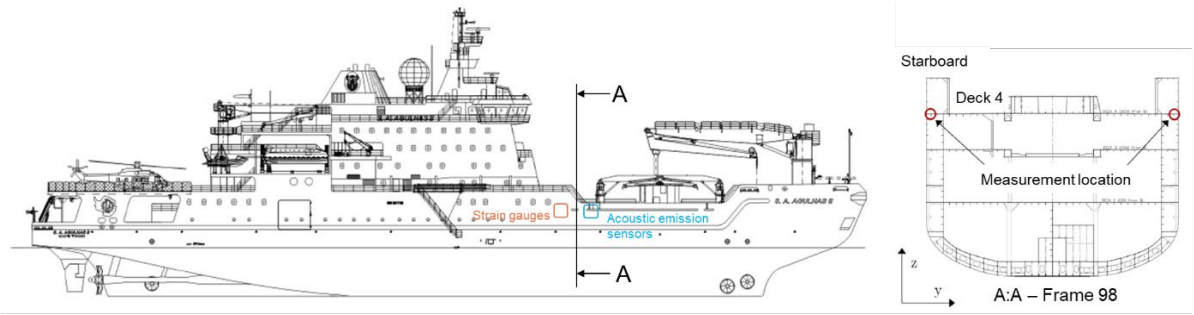


Fig. 3 Positioning of AE sensors and strain gauges and an illustrative diagram of the ship cross section at the measurement location at Frame 98 (left) adapted from STX Finland [6]

3. Instrumentation and Data Acquisition

3.1 AE System

As mentioned earlier AE monitoring system consisted of two sensor nodes installed on the port and starboard sides of the vessel. Each node was equipped with three resonant AE sensors with a central frequency of 150 kHz (type R15α), resulting in a total of six sensors. The sensors were coupled directly to the steel surface using magnetic holders and connected to AEPH5 40 dB pre-amplifiers to ensure sufficient signal amplification prior to acquisition. AE signals were recorded using an AMSY-6 data acquisition system, installed in the chain locker room to provide a protected and centrally accessible location for the acquisition hardware. BNC cables were routed from each preamplifier along the sides of the vessel to the acquisition unit, with a total cable length of 110 m per node. A schematic overview of the measurement chain including both AE sensors and strain gauges is shown in Fig. 4. Hit-based AE data were sampled at 10 MHz, while transient (waveform) data were sampled at 2.5 MHz. The acquisition was hit-based and had a rearm and duration time of 250 µs and a pre-trigger period of 400 µs. A digital band-pass filter was applied ranging from 75 kHz to 400 kHz. A fixed amplitude threshold of 45 dB was applied, with an additional condition requiring a minimum of 10 counts per hit to suppress low-amplitude noise bursts.

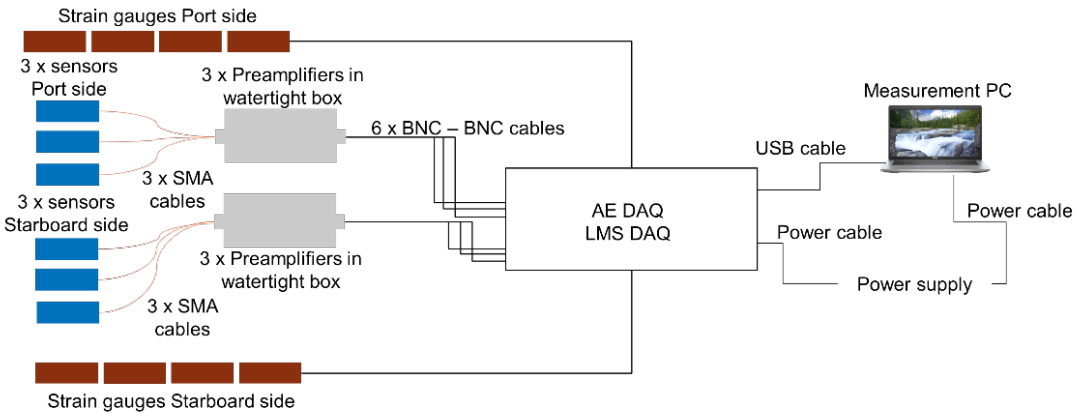


Fig. 4 Set-up of the on-board monitoring system.

3.2 Strain Gauges

Strain measurements were obtained from onboard instrumentation located in the vicinity of the monitored AE regions. The strain gauges were installed on longitudinal bulb stiffeners below the strength deck (Deck 4) at frame 98 [8], at an approximate distance of 4 m from the AE sensor locations (see Fig. 5). According to [9] the location of maximum stress from vertical bending is at Frame 98, due to the abrupt change in section modulus at the superstructure-strength deck intersection. This area has been chosen for monitoring as visible cracks repeatedly develop in the deck railing directly above the strain measurement location [8].
Strain data was sampled at a rate of 2048 Hz using an LMS SCADAS Siemens data acquisition system and a Turbine Testing software operating continuously throughout the voyage. The raw data were stored in consecutive 5-minute-long files, from which statistical descriptor moments were subsequently computed. These include the mean, median, standard deviation, minimum and maximum strain values for each 5-minute interval.

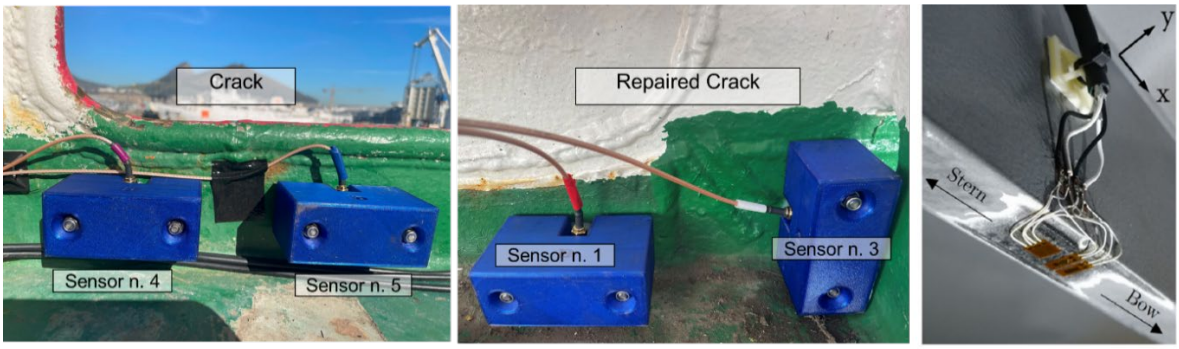


Fig. 5 (a) AE sensor placement on port side (crack) and starboard side (repaired crack). (b) A full-bridge strain gauge configuration in the void space of frame 98 [8].

3.3 GPS and Environmental Measurements

In addition to local measurements, operational and environmental data were obtained to support for the interpretation of the AE data. Position measurements were captured by the Scientific Data System (SDS), which recorded data directly from the ship's GPS at 1-minute intervals. Wave conditions, including significant wave height (H_s) and wave period (T_p), were not measured directly but were retrieved from the ERA5 reanalysis database [10]using the recorded vessel position and timestamps.

4. Results and Discussion

The data acquisition was performed in accordance with sections 3.1 to 3.3. Regarding the environmental measurements, an example of the variation in sea state conditions during the monitored period is shown in Fig. 6. An example of the variation in sea state conditions during the monitored period is shown in Fig. 6.

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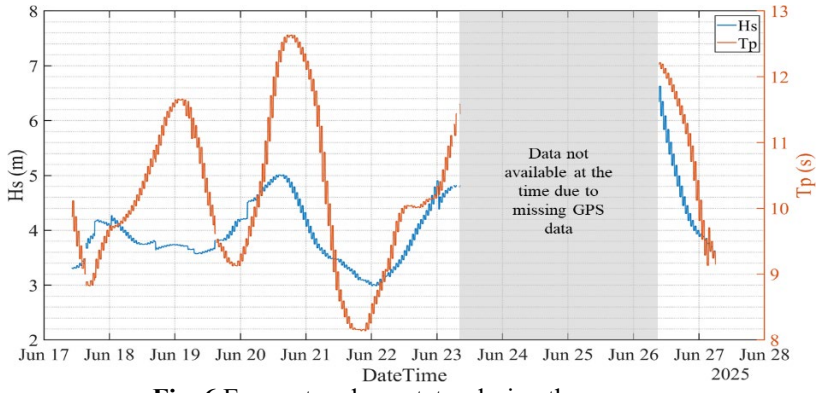


Fig. 6 Encountered sea states during the voyage.

Fig. 6. illustrates the temporal variation of the sea states during the monitored period, highlighting the presence of varying wave conditions. These environmental parameters are not analysed in depth here, but confirm that periods of elevated strain variability correspond broadly to higher sea states which are expected to influence the strain response. A period of missing data is observed due GPS information not being available at the time, which prevented the retrieval of ERA5 wave parameters for that interval between 23rd and 26th of June 2025.

4.1 AE Activity Overview

Using the procedure outlined in sections 1 and 3.1, the recorded AE signals from the port and starboard sides are analysed and compared. Under the previously stated assumptions, differences in the measured responses are primarily attributed to variations in the source term between the crack region and the repaired region. AE signals are recorded during a threshold-crossing events. Fig. 7 shows an overview of the obtained AE data across both port and starboard side sensors over the duration of the voyage. A total of approximately 4 million AE hits were recorded. Approximately 80% of total hits, were recorded on the port side node (Channels 4-6) were a visually identified fatigue crack was present, with the remaining activity distributed across the starboard side (Channels 1-3). The starboard side, corresponding to the previously repaired region, showed substantially lower activity levels. Amplitude values were predominantly distributed in the range of 50–70 dB. The port side channels also show significantly higher cumulative AE signals compared to the ones on the starboard side which exhibits a much lower cumulative number of signals consistent with a less active region.

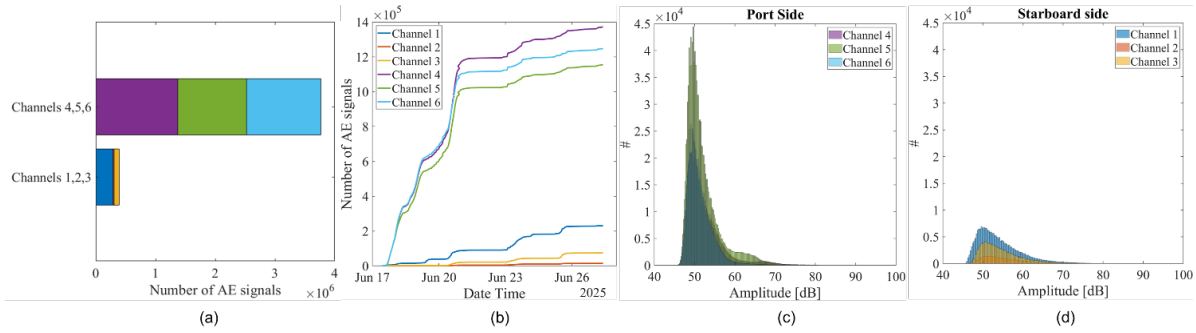


Fig. 7 Total number of AE signals (a); cumulative number of AE signals (b); AE amplitude distribution on port side (c) and AE amplitude distribution on starboard side of the ship (d).

A threshold signal-to-noise ratio (SNR) of 20 dB was used as filter to further analyze the data. Fig. 8 shows the amplitude distribution over time of the two regions. The port side shows higher, denser and more continuous activity compared to the starboard side, which exhibits a more intermittent and lower-amplitude clusters. This difference in both activity level and amplitude is consistent with the expected presence of active crack propagation on the port side and an inactive structural state on the starboard side.

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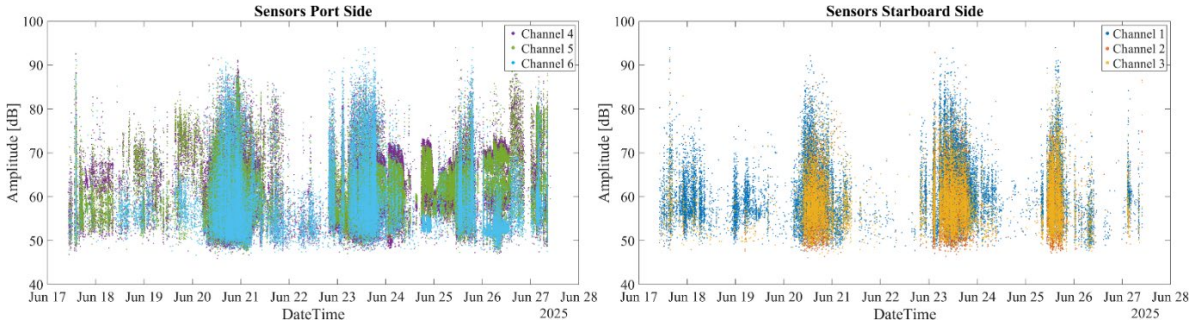


Fig. 8 Overview of AE hits measured during the voyage with SNR > 20 dB.

4.3 AE-Strain Correlation

The AE-strain correlation is also evaluated considering signals with SNR > 20 dB. AE activity is represented using the hit-rate. For the strain, the standard deviation of the measurements over the pre-specified time-window of data is indicative of the load range variability and used for comparison with AE data. Since the strain standard deviation is computed over 5-minute batches of data, AE hit-rate is also evaluated over the same 5-minute intervals to ensure consistency.

Fig. 9 illustrates the temporal evolution of hit-rate alongside strain measurements for the port side node. Hit rate evolution shows periods of elevated AE activity that broadly correlates to periods of high strain values (w1,w2,w3), suggesting a link between structural loading and possible crack-related AE. A correlation is also observed on the starboard side in these windows; however, AE activity remains significantly lower, with hit rates staying below approximately 20 hits/min compared to peaks of about 160 hits/min on the port side, suggesting insignificant crack development in comparison to the port side. These observations suggest that local damage processes on the port side are activated under higher loading conditions within the analyzed time windows. The elevated hit-rates are predominantly observed for strain standard deviations values exceeding 10 με, suggesting the possibility of identifying a threshold at the measured strain location beyond which crack growth is measured. The intervals of highest strain standard deviation also coincide with the highest recorded values of significant wave height Hs (see Fig. 6), confirming that the most severe loading conditions are driven by the encountered sea state.

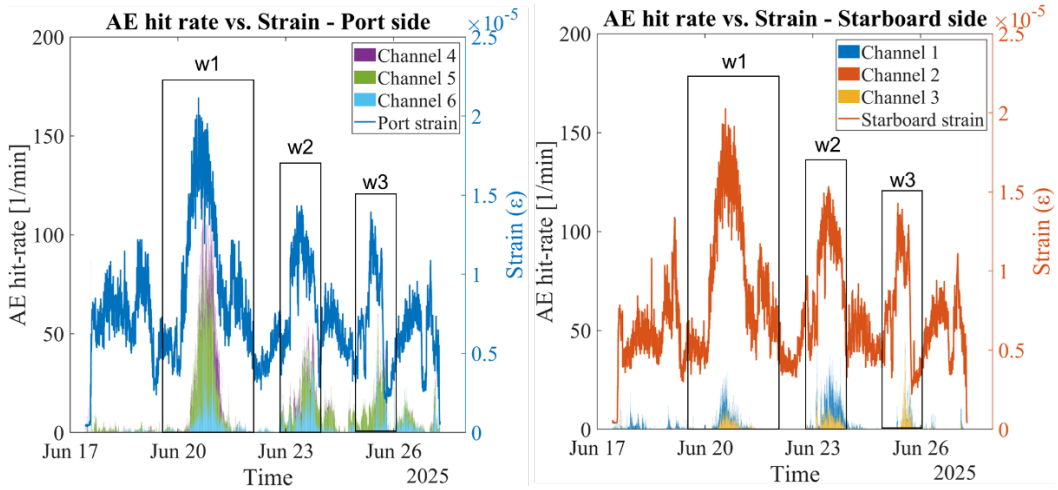


Fig. 9 Correlation between AE hit-rate and standard deviation of strain on port side (right) and starboard side (left) after applying SNR > 20 dB.

The observed AE response under real operational loading conditions demonstrates the potential of the technique to related changes in structural behaviour and loading conditions to the activation of

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localized damage processes. The application of SNR-based filtering enables the mitigation of operational noise, allowing clearer identification of relevant AE activity. In this context, the hit-rate provides a practical and effective metric to represent AE behaviour, supporting the interpretation of AE data in relation to varying loading conditions.

5. Conclusions and Future Work

An in-service AE monitoring campaign was performed on a polar vessel under operational loading conditions to investigate possible fatigue crack activity in two regions. The results demonstrate the feasibility of applying parametric AE analysis in such environments, with a clear differentiation observed between the monitored active and repaired regions. A total of about 4 million AE signals were measured throughout the voyage, of which about 80% were measured on the port side, associated with the presence of a known crack. The comparison with strain measurements provides valuable insights about when the cracks indicate growth, based on the interpretation of higher levels of AE activity, with hit-rates up to 160 hits/min in relation to varying loading conditions. Overall, the findings highlight the potential of AE monitoring as a promising tool for identifying and tracking damage in real structural members. Future work will focus on extending the analysis beyond parametric indicators, including waveform-based approaches and feature extraction methods, to further improve the characterization of damage based on AE signals. Further correlation with other environmental and operational conditions will be made.

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