Adulteration of underwater acoustic measurements

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Abstract

The influence of the marine environment caused by radiated sound of ships has become in the focus of research and surveillance programs. Besides the underwater acoustic surveillance measures to control the underwater noise contribution of ships shall be initiated. Identified as a prerequisite, a standard for measurement has to be issued. In a joint working group, within the ISO (International Organization for Standardization) efforts and demands are announced to establish standardization for ship measurements. This paper will describe underwater range facilities in northern Europe owned by the government and operated by the MoD. The experiences depict the difficulties of reproducibility and comparability according to procedures, environmental effects and range equipment.

Keywords: range comparison, underwater acoustic measurement

1. Introduction

The possibilities of global trade, international merchandising and shifting the productions lines to foreign countries subsequently lead to the increase of international shipping traffic lanes. The influence on the marine environment caused by radiated sound of the ships has become in the focus of research and surveillance programs and therefore a multitude of groups are deploying sensors systems in the corresponding areas.

Regarding the diverse influences on each measurement campaign the results of suitable and repeatable performances could vary enormously according to the used measurement- and analysis procedure, the local and time dependent environment, the distance sensor to ship, aspect angle and of course to the properties of the used technical system. Based on these impacts the outcome of corresponding research and surveillance programs might lead to discussions in the international forum.

International environmental groups have initiated a Marine Environment Protection Commitee within the IMO (International Maritime Organization) to reduce shipping noise. Identified as a prerequisite, a standard for measurement has to be issued. In a joint working group, within the ISO (International Organization for Standardization) efforts and demands will be harmonized to establish standardization for ship measurements[1].

Generating results by one underwater acoustic measurement system or another system could encounter an immense difference.

The influence of sea bottom especially at a shallow water range could be massive. The example in figure 1 shows the same ship measured at two sites with a different sea bottom consistency. The gassy mud ground attenuates the frequencies from 16-25 Hz compared to a sandy bottom.

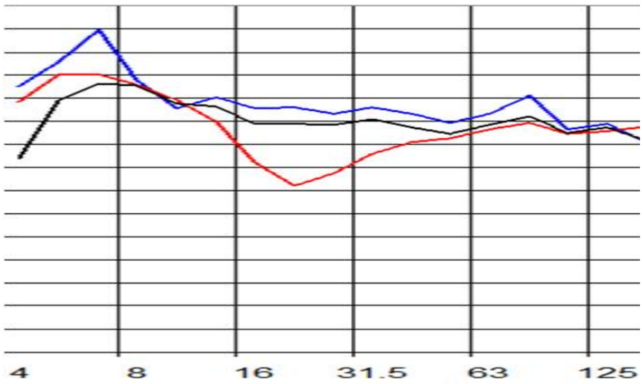


Figure 1: Same source at different measurement sites

2. Reproducibility

Each underwater range facility has its own characteristics. The water depth, bottom type and the geometry of the sensor layout are the main contributors to characterize an underwater acoustic measurement at a specific location. Other influences, e.g. water consistency or the actual diurnal variations are disregarded. In general and acknowledged within the underwater acoustic community as well as established in navy standards the underwater radiated sound registered by calibrated hydrophones will express as dB levels in the following form:

$$Sound\ Pressure\ level[dB] = 20\ log_{10}\left(\frac{p_{RMS}}{p_0}\right)\ with\ p_0\ = 1\mu Pa \tag{1}$$

The distance between the hydrophone and the noise source is not included and is considered by using the passive SONAR equation :

$$SL = SPL(r) + \ PL(r)\quad [dB\ re\ 1\mu Pa^2\ m^2] \tag{2}$$

PL(r) refers to the propagation loss over the distance r between hydrophone and noise source. The propagation loss includes all influence mechanism which occurs during the noise registration. The source level (SL) manifests the level in dB re 1µPa re 1m regardless whether near field or far field condition during the ranging. Of course the registered noise in the near field will differ compared to the far field registration (distance corrected). Avoiding the near field properties could be possible by a sufficient distance between the noise source and sensor but it would contradict the evaluation of the radiated noise due to the insufficient signal/noise ratio.

2.1. UW Signature Ranges operated by WTD 71

Regarding the possibilities of an acoustic measurement the WTD 71 operates a shallow water range and a deep water range. The shallow water range is located in the Eckernfoerder Bay in North

[1] „International Standardisierung zur Vermessung des abgestrahlten Wasserschalls von Handelsschiffen", Anton Homm, DAG 2014

Germany and consists of several measurement sites. Perpendicular to the track line 5 hydrophones are deployed at the two main sites. The hydrophones are lined in a distance of 40 m to the port side and starboard side direction starting on the track line. The water depth is 18-22 m. The sea bottom differs at the two main sites significantly. Besides the hydrophones further sensors for the underwater signature are installed. In cooperation with NOR, NDL and DEU a deep water underwater acoustic range was established in Norway. Three winch operated strings, with 3 hydrophones each, are deployed in a sheltered fjord with a water depth of 390 m. The usable depth range of the hydrophones is about 20m to 200m. The sea bottom consists of a sand layer on rock. The width of the fjord in the operational area is 1. 5 km. The strings comprise according to the track line an entrance of 216 m width.

2.2. Influences

Repeating the equal runs of the underwater acoustic measurement of the same ship could differ in the comparisons according to the following factors[2]:

1. Propagation loss assumption (differences in water depth, hydrophone depth, water properties and sea bottom)
2. Measurement distance ship-hydrophone (near field or far field) , aspect angle, assumption of omni- directivity
3. Noise producing mechanism could differ from time to time, operating mode includes automatic starting processes which are not included in all the repeated runs
4. Cavitations process is dependent on the water consistencies, draft of the ship (different load) , current effects
5. Technical measurement system, layout or grid of the hydrophone deployed under water in aspect of the track line
6. Procedure of the analyzing- process, accuracy of the tracking system, calibration procedure

These factors have a direct relation to the formula 2. The bullets 1, 2 and 4 refer to the second part while bullets 5 and 6 refer to the first part of the equation.

The influences of the first and the second bullet could be estimated by different models. The numerical simulation depends on the a-priori factors of the range environment as well as the geometry of the range and it is frequency dependent. In the lower frequency bands the levels exceed the spherical spreading loss of *20 log (r)* mainly due to the LLM[3] effect. The accuracy of this kind of estimation is influenced by the model itself and the input parameter. Unknown or only vague input parameters mitigate the accuracy of the model. In the most cases the simulations are performed by assumptions to simplify the process. Averaging and repetition could mitigate these variations.

2.3. Simplification

For practical reasons and as a good adjustment the propagation loss will be assumed by

$$20 * log_{10}\ (r)$$

[2] TNO 2012 R10075, AMP 15 noise range calibration –Part 1

[3] Lloyd mirror effect

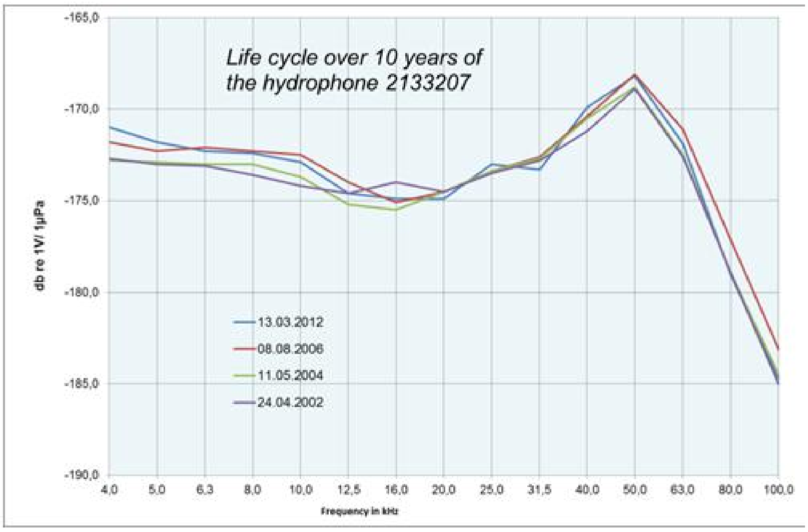
This approach enables to establish underwater acoustic range procedures at least for the individual range. Results obtained at different ranges could be comparable when the geometry of the sensor-layout, the environment properties are similar and the analysis-procedure is the same.

2.4. Computational parameters

The comparability of the underwater radiated noise of the identical source at the same range and same sensor could differ tremendously by using different procedures.

$$SL = \boldsymbol{SPL(r)} + PL(r) \quad [dB\ re\ 1\mu Pa^2\ m^2]$$

The processed SPL(r) includes all properties of the technical equipment (sensitivity correction values) and procedures. System calibrations could differ from time to time depending on the signal transfer path as well of the hydrophone calibration equipment.



Hydrophones-calibration results with a tonal deviation shall not be used for signature measurement. Deployed calibrated hydrophones at the same range should show concluded results. Therefore a range should be equipped with a minimum of 3 hydrophones.

Figure 2 illustrates the results of the reciprocity calibration of one hydrophone over a time period of 10 years. It shows variations less than 1.5 dB

When transforming the time raw data into 1/3 octave bands for each second by using the narrow band algorithm FFT or the digital 1/3 octave band filter the results could already differ. The narrow band method with its constant bandwidth has to be adjusted to the relative band width of the 1/3 octave band. Furthermore the corresponding sensitivity data sets of the hydrophones are normally calibrated in the 1/3 octave frequency bands.

The processing of the computed 1sec spectra could be performed also by a multitude of possibilities. The actual time window for this kind of processing could embrace the duration of the ship passing over the sensors or only during a selective time period. The ship length and the speed are the main parameters for this kind of variations.

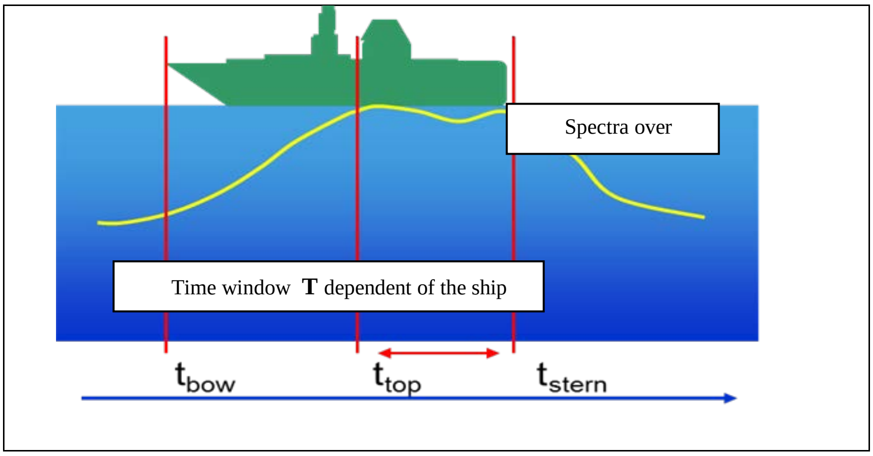
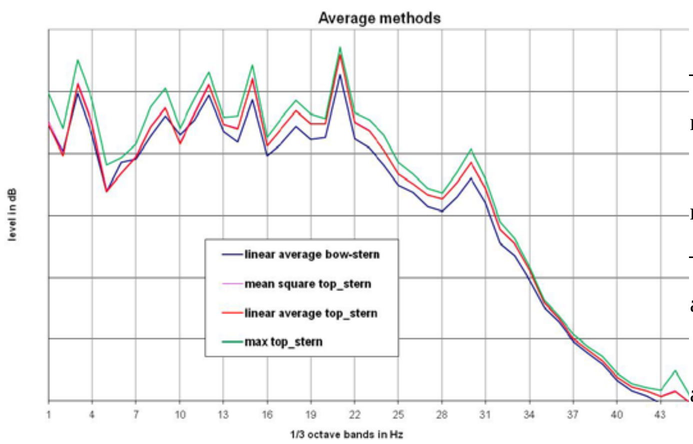


Figure 3: assessment to determine the duration of the time window

Obviously the averaging method, for the chosen time window affects the level of the spectra

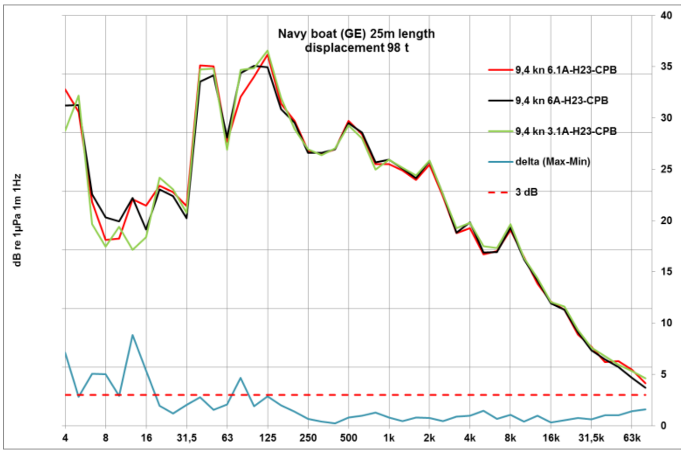


Max	$L_{max} = 10 * \log(\frac{{}_{i=1}^{n}\max(p_i)}{p_0})$
Mean square	$L_{ms} = 20 * log \frac{\sqrt{\frac{1}{n} * \sum_{i=1}^{n} {p_i}^2}}{p_0}$
Linear average	$L_{la} = 20 * \log\ (\frac{1}{n} * \frac{\sum_{i=1}^{n} p_i}{p_0})$

Figure 4: by using different average methods or time windows the result differs about 3 dB

3. Quality of the noise source

The noise generating devices of a ship/boat are set to the highest degree by the automatic procedures. For a requested configuration (propulsion system, speed, aggregates) the ship should sail in a steady state condition without any correction procedures e.g. rudder movements. Variation still occurs from time to time. Reproducibility will be influenced by these effects. Deviations of the track line (different aspect angle) and the consideration of the swell also produce dissimilarity.



Repeating the runs of a small navy boat set at the unchanged operating condition and sailing in the same direction at the shallow water range Aschau (GE) referred to 1m showing deviations in the 1/3 octave band analysis less than 3 dB (f> 31,5Hz). Propagation below 31,5 Hz varies in a higher dimension than expected due to the near field condition. Runs with higher deviations were excluded.

Figure 5: deviations of repeated runs

The necessity of repetition and averaging of runs mitigates these variances as performed during an international measurement campaign with the same ships at different range facilities and supplies sufficient comparable results.

4. Comparison of UW measurements at different location with the same sources

Manifesting the influences of the local environment and propagation effects, the same sound sources were measured at different range facilities. The sources sailed in a short time period to the different range facilities, so that the noise producing components are conducting the same way. The identical procedures and analyzed processes were utilized at the different ranges. Concentrating on the reproducible runs, a comparison was performed on the consistent high-quality data sets.

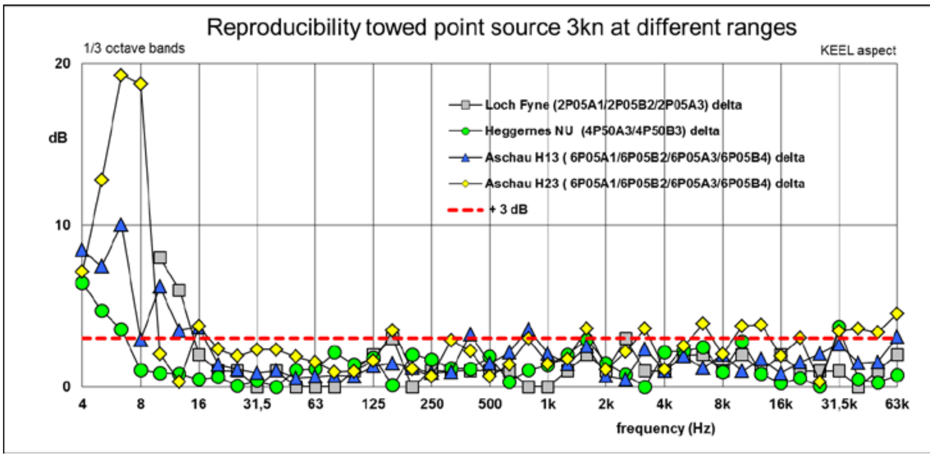


Figure 6: average of the towed noise source 80m behind the towing ship at different ranges[4]

The measurement depths were similar. The influence of the source itself is shown in figure 6 and 7. The point source varies more in the high frequency bands while the distributed source (research vessel) varies in the low frequency bands. After all, the variation at each range is within 3 dB at least above 100 Hz. The deep water ranges show a slight minor variation.

[4] Data sets accomplished during the RIMPASSE(NATO project) trials in 2011

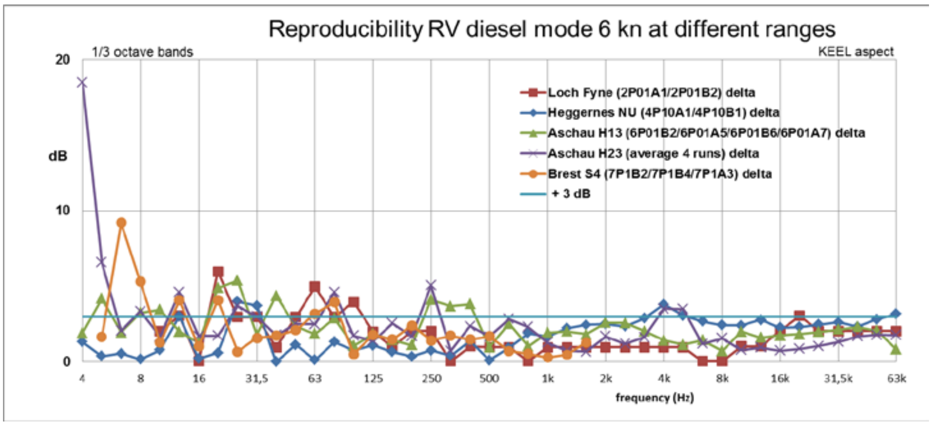


Figure 7: average of the diesel mode runs of RV with 6 kn at different ranges

5. Comparison of different UW measurement systems at one location with the same sources

The deviation, by using different measurement systems for the evaluation of the radiated noise of a ship, should be negligible. Regarding the influences mentioned in **2.2** only the processing procedures and the technical equipment are controllable. In the scope of an international project different international mobile underwater measurement systems had to be compared. The mobile systems of three nations were deployed at the underwater signature range of the WTD 71 in Aschau (Eckernfoerder Bay). The mobile UW-systems were laid out in one line, (track-line), in a distance up to 400m to the reference system. The layout can be seen in figure 8.

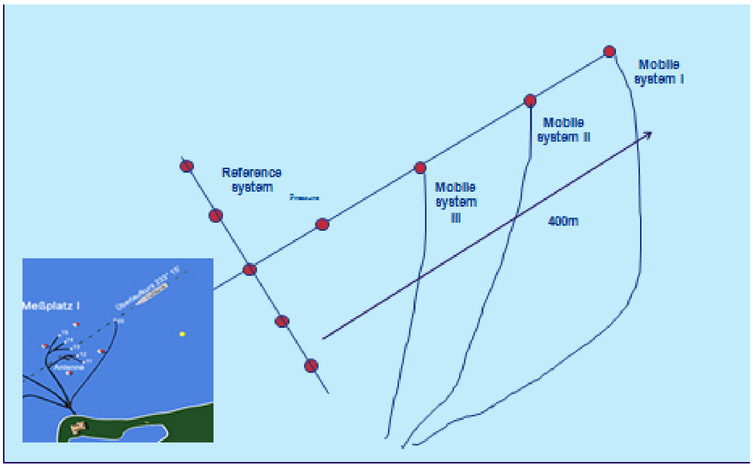


Figure 8: Layout of the deployment of the Uw-mobile systems

The ships sailed several times in the same operational mode over all systems. The aspect angle and the distance of ship/sensor varied with the track deviations. The controlled runs were tracked by DGPS. Runs with deviation over 5m off track were dismissed. The influence of the aspect angle in these cases could be neglected. The radiated noise level in this comparison was not corrected to 1m. Corrections for the distance or the amplifications would produce a constant offset..

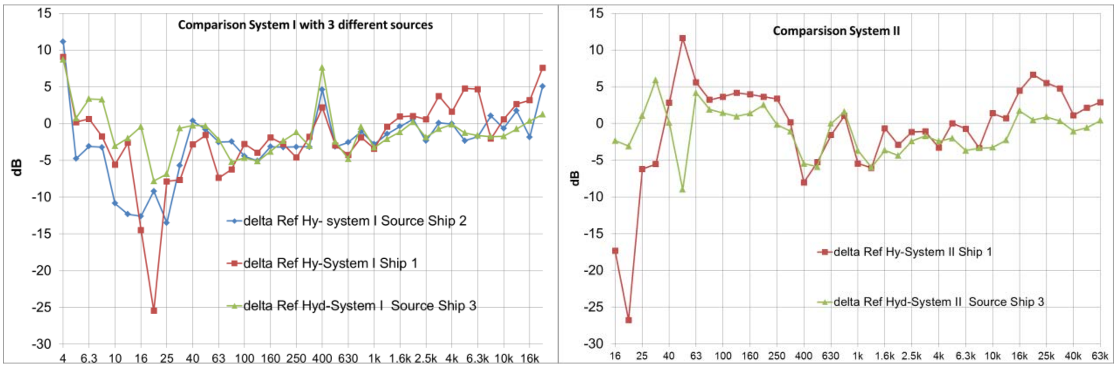


Figure 9: a) Comparison with 3 different sources for system I; b)-with two different sources system III

The comparison is based on so called quick look results. The analyses are processed by formula 1 and corrected by the individual sensitivity. The duration of the time window (T[5]) includes the ship length plus 2-3 sec after stern. Several runs of one configuration, analyzed by formula (1), were averaged for each system and applied as basis for the comparison.

$$RNL(f) = max_t \; OTO \; (f, T)$$
$$OTO(one\ Third\ Octave\ \ spectrum); RNL(\ Radiated\ Noise\ Level)$$

The obvious deviation of isolated frequency bands in Figure 9 (left) of one system in reference to the Aschau range has to be distinguished in lower and higher frequencies. The variation in this comparison was expected to be much lower. For three different sources (ships) the differences between the reference hydrophone and the mobile system tend to the same deviation. The huge significant deviation in the low frequencies up to 31 Hz seems to be caused by the sea bottom. The major part of the Eckernfoerder Bay has a muddy and gassy sea bottom. The influence of the bottom properties at the reference hydrophone is prominent. Further investigations will explain a possible different sea bottom effect in 400m distance to the reference system. The isolated deviations in the frequency range from 50Hz-20 kHz are most likely not originated by the sea bottom or by the source. The repeatability of the runs was within 2-3 dB in this frequency range. The similar shape of the deviation for three different sources looks as it was inherent in the system. Most likely technical properties or the data processing caused the differences. The calibration and frequency response measurement of the different systems were performed at different institutes. Results, obtained by the two other mobile systems, vary in a different way, which excludes possible causes by the reference system. Detailed analyses and investigations are ongoing within the international project to explain the differences. Especially in case of contracted radiated noise limitations for ships, approved by the international community, uncertainties in the technical systems should be minimized.

6. Conclusion

There are several effects which will influence an underwater measurement result. Besides the environment, aspect angle, distance sensor –source and the source configurations, the measurement system itself will influence the results. Focusing on the technical system, in addition to the calibration of the sensor a system calibration from end to end is mandatory.

The mitigation of the variation during an underwater measurement campaign could be achieved by averaging the runs with the same configuration. Applying several hydrophones during one run is recommendable. Repetitions are necessary.

[5] Time raw signal computed for each sec. , T duration of window over spectra

Taking into account model based values for the PL, the results would differ even more to the uncertainty of the model simulation. Excluding the real propagation loss (PL) by using the simplified PL =20 log r, measurement results in keel aspect for the same sources gained at different ranges processed by the identical procedure could be within a 5 dB variation at the low frequency bands and 3 dB for the frequency bands over 100 Hz. The comparison prerequisites are the similar sensor depths and the comparable sea bottom properties at shallow water ranges.

Experienced knowledge and the possibility to compare several hydrophones at one location by using a controlled source, procedure within WTD 71, exclude hydrophones with an unusual behavior. The comparison of different underwater measurement systems within the project SIRAMIS at one range facility and by using the same controlled sources shows higher deviation than expected. Different calibration methods at different institutes as well as system immanent properties and analyzing procedures could be an explanation. In the low frequency band the sea bottom has the most prominent influence. Further investigation will be performed.

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