24th INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
23–27 July 2017, London

EVALUATION OF AIRBORNE NOISE DUE TO NAVIGATION AND MANOEUVRING OF LARGE VESSELS

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Airborne noise produced by large vessels during navigation procedures and manoeuvres while approaching harbours could be critical when the surrounding areas are residential or naturalistic, e.g. harbours situated inside lagoons or on wide rivers. The characterization of sound power emitted by large vessels is important also when noise predictions need to be made. Noise measurements during transit should define the main sound sources of the vessels, where they are located and their directivity. This is generally quite difficult due to several aspects related to the distance and the height of the reception positions required for the correct evaluation of the directivity of the source and the presence of residual noise determined by other sources. Technical standards are not useful in these cases because they aim to define the evaluation procedure for specific types of ships, mainly small, during mooring or manoeuvring at a short distance from the pier. In the present paper an analysis of experimental measurements for the evaluation of airborne noise due to navigation and manoeuvring of large vessels is reported, with particular reference to cruise ship pass-bys observed from different monitoring positions.

Keywords: Large vessels, Airborne noise, Noise measurements, Sound sources

1. Introduction

The navigation of large vessels could cause noise pollution at great distance, because of the height of the noise sources and the low frequency components produced by the generators [1]. The issue could be critical when the surrounding areas are residential or naturalistic, e.g. harbours situated inside lagoons or on wide rivers. In fact, at reduced distances, not only are the main low frequency sources critical; so are the secondary sources related to the ventilation, air conditioning and climate control of the ship’s indoor environment. Despite a number of studies, researchers have clearly highlighted the inadequacy of the current measurement and evaluation techniques available for the characterization and prediction of airborne noise emitted from ships both at sea and while manoeuvring or mooring [2÷16].

In a previous research study [17], the authors described the methods for the assessment of sound power emitted by moored ships. In this paper the results of measurements and evaluation of noise emitted by large vessels during navigation are reported. In order to acoustically characterize the cruise and industrial ships in transit, long-period noise monitoring was carried out together with short-term measurements; this way it was possible to compare and validate the data obtained in the long-term measurement positions, made without the presence of the operator. The acoustic characterization was made during different periods, using various locations.

During the measurement campaign the emission of various types of ships, including large commercial and industrial vessels, tourist boats, taxis, ferries, etc. were recorded and analysed. In this paper the evaluation of airborne noise due to navigation and manoeuvring of large vessels is reported, with particular reference to cruise ship pass-bys observed from different monitoring positions situated at different heights.

2. Noise measurements during transit of the cruise ships

For the acoustic characterisation of cruise ships, noise monitoring was conducted in a lagoon area in October 2015. Four different long-term measurement locations were used but the reference data for the characterization of the ships were taken primarily from two positions where it was possible to detect a certain number of transits little affected by other noise sources. The two positions were located at different heights (respectively about 19 m and 6 m from the zero reference for the water level) in the two opposite sides of the lagoon inlet. These two heights were chosen to verify possible directivity effects in the noise emission of the cruises. In the area where the measurements were performed, the average speed of the cruise ships is about 8 knots.

The acoustic characterization of the cruise ships was made by processing the noise monitoring data obtained at the two measurement stations, through recognition of individual transits using the temporal graphs of noise spectra in third octave bands (spectrograms). In order to distinguish the passages of these ships from other noise sources, the transits were monitored directly by two operators during the passage of vessels entering or leaving the lagoon, or recorded using the Marine-Traffic website [18], which provides information in real-time on the position and speed of vessels.

Table 1 shows the values of the main acoustic parameters obtained from the cruise ship passages. In this table, only transits not significantly affected by other noise sources have been reported. For repeated passages of the same vessel, the average value was reported and the number of passages indicated in brackets.

Table 1: List of cruise ships, number of passages, distance and main acoustical parameters.

	Position 1 (h=6m)			Position 2 (h=19m)		
Name of the vessel and number of passages	**distance [m]**	**L_{Aeq} avg [dB(A)]**	**SEL [dB(A)]**	**distance [m]**	**L_{Aeq} avg [dB(A)]**	**SEL [dB(A)]**
ARTANIA (2)	150	60,7	86,3	160	59,1	84,2
COSTA DELIZIOSA (4)	150	56,8	78,1	160	57,2	80,7
COSTA MEDITERRANEA (4)	150	56,7	81,4	160	54,2	79,0
COSTA NEOCLASSICA (2)	150	60,9	85,7	160	58,0	81,2
ISLAND PRINCESS (2)	150	--	--	160	57,6	80,1
MSC MAGNIFICA (4)	150	56,2	81,5	160	55,0	79,2
MSC MUSICA (3)	150	56,7	79,3	160	55,3	78,9
MSC OPERA (1)	150	57,7	78,3	160	56,5	83,3
MSC POESIA (3)	150	58,4	83,3	160	57,8	81,6
NORWEGIAN JADE (4)	150	56,3	78,6	160	56,1	79,0
OCEANA (1)	150	58,6	82,4	160	55,6	79,9
QUEEN ELIZABETH (1)	150	55,8	79,0	160	54,7	77,3
SPLENDOUR OF THE SEAS (2)	150	57,0	78,8	160	55,7	77,3
THOMSON MAJESTY (4)	150	55,7	78,8	160	56,5	78,5
VIKING STAR (2)	150	58,8	81,4	160	56,5	80,0
VISION OF THE SEAS (1)	150	53,2	74,0	160	53,8	76,1

During the monitoring sessions some relevant information on the vessels' characteristics were collected (dimensions and tonnage), as well as weather conditions and direction of the cruise ships. Of significant importance was the measurement conditions with respect to other external noise sources, in particular the possible contribution of the tugboats and pilot boats which were always present nearby. Although, in the area chosen for the measurements, the tugboats were not connected to the cruise ships, and most of the time navigated at a large enough distance to exclude any contributions on the measurements, in some cases the measurements were compromised by their presence and other vessels (tourist boats, taxis, small commercial vessels, etc.). In this study, only transits not significantly affected by other noise sources have been considered, although, due to the heavy navigation traffic, the complete exclusion of any other noise source was not possible.

The acoustical parameters were recorded every second. In the post-elaboration the spectrum, LAeq and SEL were calculated considering the time related to the single transit. Figure 1 shows the spectra, in term of SEL, from the cruise ship passages, identified with the three different methodologies mentioned above. Therefore, the results should be considered on average, and the difference between the spectra of the ships could be due to different manoeuvrings and different velocities.

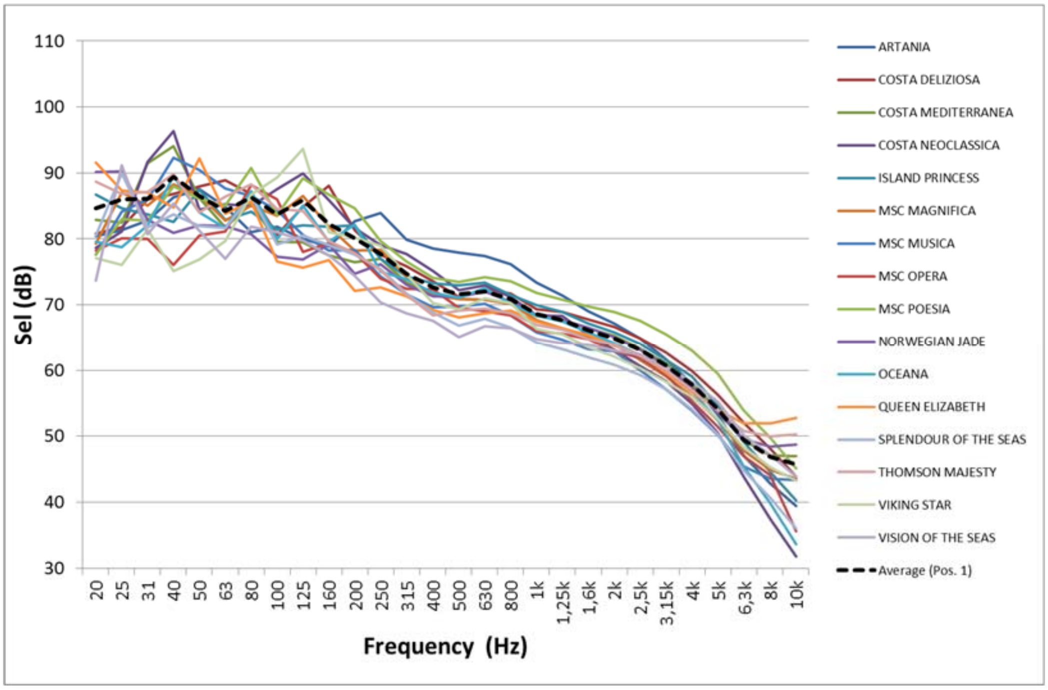

Figure 1. Spectra (SEL) of cruise ships detected during the measurement campaign, in position 2 (h=19m).

3. Considerations on noise emitted by cruise ship pass-bys

The results of the measurements, as shown in figure 2, exclude significant effects of the vertical source directivity, although they are not completely equivalent. On average, the difference is approximately 1.5 dB. Considering that the comparison was made using the logarithmic average of all passages of the cruise ships considered, the difference, more or less constant for all frequencies, could be determined by the specific passages and not by the different heights. This consideration could be made at least for distances greater than 150 m, which was the distance of the measurements. We also have to consider that the difference between the distances of the two positions was approximately 10m and the closest position had the higher level.

Considering also the contribution of tugboats, always present, it is shown that the increase is approximately 2 dB on average, more evident at low frequencies. Therefore, the contribution of the tugboat in not negligible and thus it should be included in the simulations.

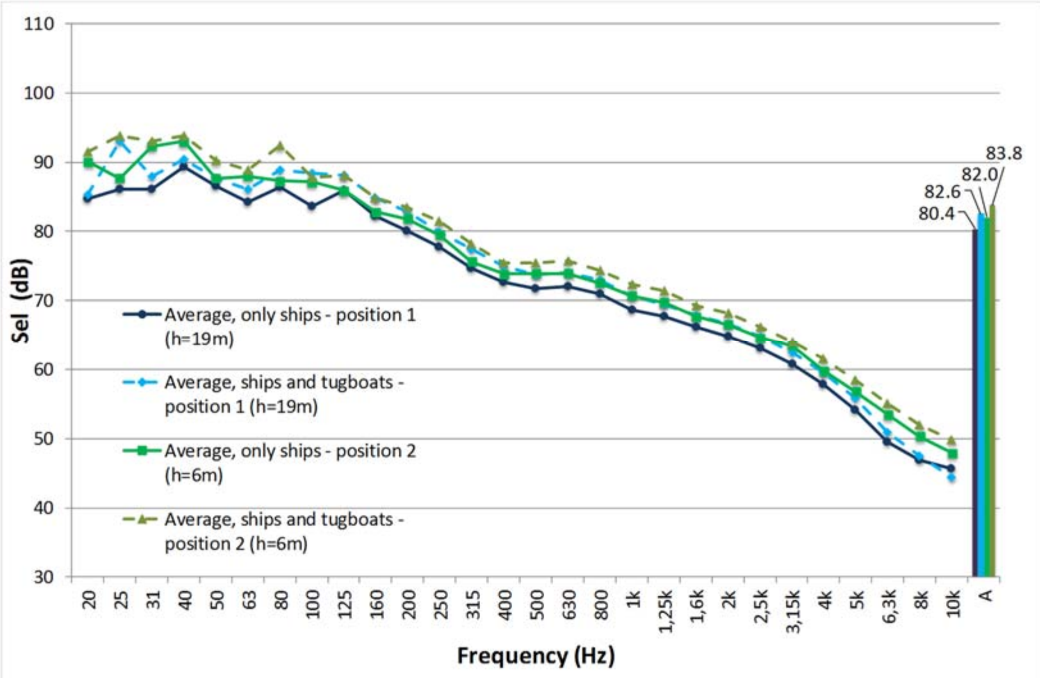

Figure 2. Comparison between the spectra (SEL) calculated in two different measurement positions, without and with the contribution of the tugboats.

In figure 3 a comparison between the spectra (SEL) of a cruise ship and a tourist boat, having approximately the same SEL in dB(A), is reported. Despite its much smaller size, the tourist vessel has a very pronounced low-frequency emission, in particular at 80 Hz. This feature of the spectrum results in a much more pronounced perception and disturbance compared to the cruise ship.

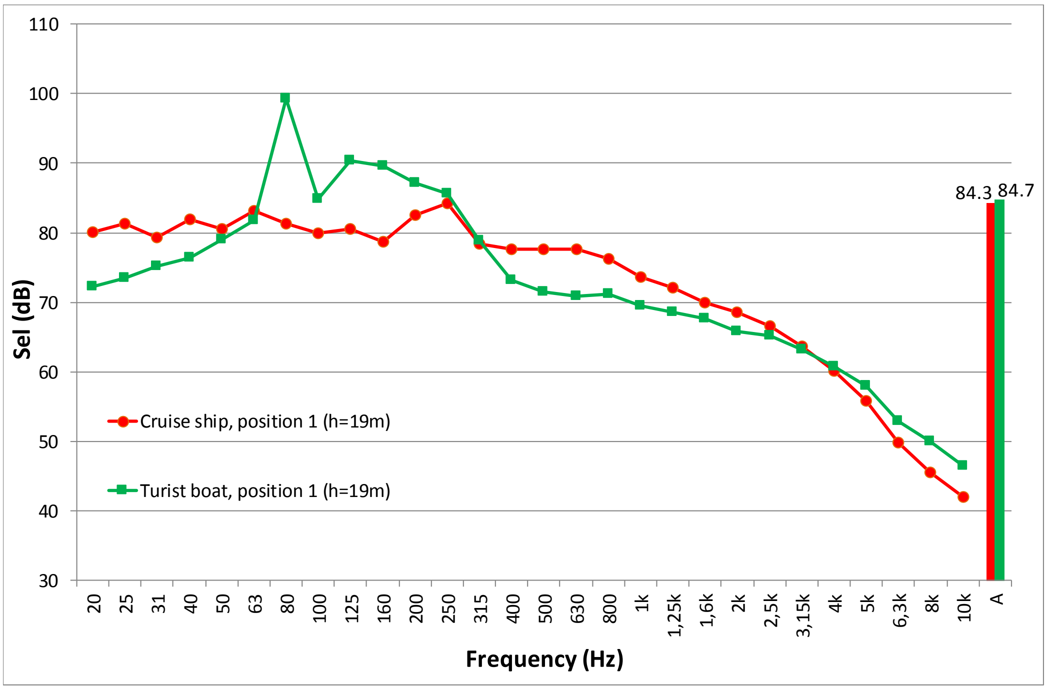

Figure 3. Comparison between the spectra (SEL) of a cruise ship and a tourist boat having approximately the same SEL in dB(A).

4. Procedures to perform noise simulations for large ships

Considering that there are no international standards to be used for the simulation of noise propagation from vessels, it is possible to use the ISO 9613-2 [19] while for the modelling of the sound source referring to the transit of ships, it is possible to use linear sources placed at different heights, by calibrating the model based on experimental measurements. The prediction software available on the market generally use ray-tracing algorithms and allow the simulation of very complex situations including a large number of sources and receivers extended over very large areas. The calibration of the sound sources for commercial and cruise ships can be made following the procedure described below, already used by the authors. The data measured by one of the monitoring units have been used in order to determine the vessels' acoustic input data, necessary to implement the simulation model. The data collected by the second measurement unit were then used to check the correct calibration of the model.

Sound spectra were acquired in third octave bands for the individual ship pass-bys and, considering the duration of each transit, the SEL was calculated; an average SEL was then calculated as an logarithmic mean of several transits; the calculated standard deviation was about 3 dB (A), which means that the vessels can be properly grouped in the same category of sources. The simulation software was then used to reproduce exactly the situation during the noise measurement considering the Digital Ground Model, with the water, ground, buildings, roads and waterways added. A calculation was then performed with a dummy source having the same sound power per unit length in all of the third octave bands considered. The difference between the sound power value applied to the source and the one measured in the receiver point was due to all the attenuation components considered in ISO 9613-2. The difference thus calculated was applied to the sound spectrum of the SEL of an "average vessel", previously obtained from the measured data, which was then converted into a daytime LAeq relative to the transit of a single vessel. Finally LAeq in the second receiver location was calculated from the sound power per unit length. This procedure provided an accurate approximation of the LAeq, since a maximum difference about 1 dB was found between measurements and simulated results. The calculation model was therefore considered valid for use in other simulations in the same area with different traffic.

5. Conclusion

The characterization of the noise emission of large vessels during navigation and manoeuvring a relative young field of application [20], but is important in order to estimate the total sound power to be used for simulations. However, specific technical standards for the measurement procedures and for the implementation of the characteristics regarding emission in prediction models are not yet available. Furthermore, experimental characterization during navigation is not an easy task for large ships, in particular due to the difficulties in finding places at a relatively close distance and with the absence of other external noise sources. Another issue is to find the right procedures to characterise the total sound power and the different contributions of the various noise sources on a large vessel during navigation.

In the present paper the results of noise measurements of large vessels, in particular cruise ships, was presented in order to contribute to finding the best procedures for this type of ship. From the results it was possible to exclude any relevant effect of noise directivity, at least for a distance above 150 m, and for not particularly high buildings and places in the surrounded area. Furthermore, in order to use the data for simulation, it is important to consider also the tugboats and the other supporting boats close to large vessels during their approach to the harbours located in proximity of residential areas or protected natural areas.

In order to follow common procedures, a new series of technical standards for the estimation of the total sound power emitted would be useful, considering also the different sound emission characteristics during navigation, manoeuvring and mooring. These procedures could be obtained taking into account the particular geometry of the site and the size of the source, using a variety of measurement and evaluation techniques for obtaining reliable assessments of the noise emission of large ships. The use of other qualitative assessment techniques (e.g.: source localization, beamforming, etc.) can provide a further support to carry out reliable sound pressure level measurements.

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