Freefield Measurements of Radiated and Structure Borne Sound of a Ship

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Introduction

Generally, a ship has to be considered as a non-compact source region with complex sound propagation processes inside the structure. Moreover, there are unsteady structural loads because of the sea state. Once radiated from the ship, the signal detected somewhere in the ocean depends on the properties of the medium, i.e. ocean stratification, transmission loss, reverberation, bottom properties, sea state and ambient noise. Although there is a variety of effects, the measured radiated sound is caused and therefore determined by the ship's sound sources in some way or another.

The radiation of simple sources is described very well [1] and simple radiating structures can be treated numerically [2]. But there is actually no reliable model, which allows to predict the radiated underwater sound of a complex structure, like a ship. Advances in measurement instrumentation, especially the simultaneous registration of a large number of sensors give new motivation to investigate the relation between structure borne sound and radiated sound in empirical manner.

Experimental

As mentioned above, the measured underwater sound is influenced by many effects. An important and only difficult to estimate effect is caused by the bottom. In order to eliminate this effect, the measurements were carried out in deep water (Celtic Sea, depth about 1000 m), i.e. under freefield conditions. The experimental configuration is shown in fig. 1. The research vessel "PLANET" passed our new developed Autonomous Vertical Array Buoy with constant speed at a distance between 30 and 300 m (closest point of approach, CPA). The trials were run at different speeds and distances.

The Autonomous Vertical Array Buoy is a freely drifting system, which allows to measure the underwater sound by means of a vertical hydrophone line array. An important advantage of this system is, that there is no second ship required to carry out the measurements. The Autonomous Vertical Array Buoy (s. fig. 1) consists of a radio buoy (①) and a subsurface unit (②) connected by an electro optical cable (③). The vertical hydrophone line array (④) consists of an elastic hose containing 128 hydrophones, which can be combined to 3 lines of 64 staves (nested array). These 3 lines are designed for different frequency ranges up to 5 kHz. The measured acoustical and non-acoustical data are recorded with a sampling rate of 15625 Hz. The raw data are stored completely in the subsurface unit (②). Selected data can be transferred via WLAN to the laboratory at PLANET for quick look analysis. The Autonomous Vertical Array Buoy is controlled via WLAN, VHF-radio or ORBCOMM. The power supply allows an autonomous operating time up to 8 hours.

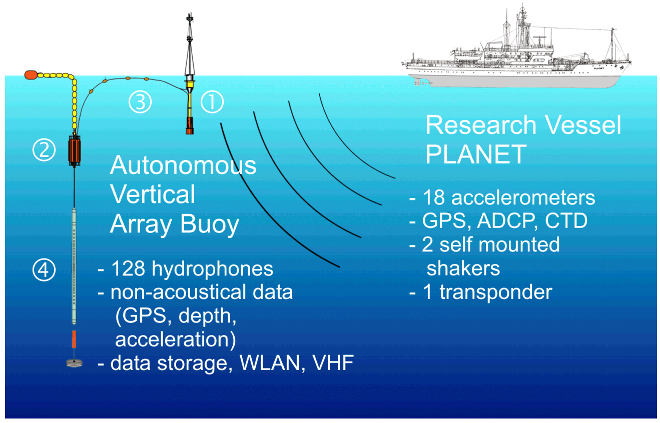

Figure 1: Experimental configuration for the trials in the Celtic Sea, September 2003. ① radio buoy, ② subsurface unit, ③ electro optical cable, ④ vertical hydrophone line array, ADCP: Acoustic Doppler Current Profiler, CTD: Conductivity-Temperature-Density probe

The research vessel PLANET was equipped with 18 accelerometers on starboard below the waterline. They were placed on selected frames and foundations of aggregates, such as one diesel generator, the electric propulsion motor, a cooling pump, a transformer and the thrust-bearing (fig. 2). In addition to the ship's sound sources, defined signals were generated by two self mounted shakers (fig. 2). The water current and the ocean stratification were measured by an Acoustic Doppler Current Profiler (ADCP) and a Conductivity-Temperature-Density probe (CTD). The ship data and the array data were synchronised by means of a trigger signal and 4 kHz pulses from a transponder. From the time delay of the transponder pulse the distance between the ship and the array was calculated.

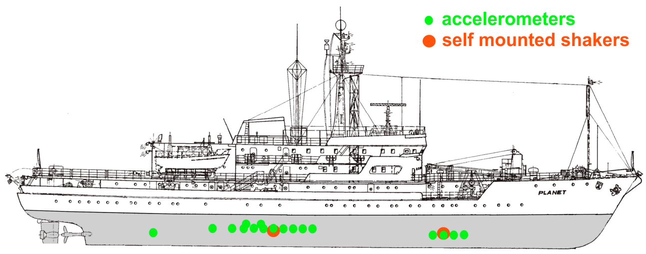

Figure 2: Schematic drawing of the research vessel PLANET, Positions of the self mounted shakers and the accelerometers inside the hull on starboard. 13 accelerometers were placed on frames, the others were fixed on foundations of aggregates (diesel generator, propulsion motor, cooling pump, shaft-bearing, transformer)

Results and Discussion

Structure Borne Sound

For a ship's speed of about 3 knots, fig. 3 shows typical velocity spectra from selected points: diesel generator, propulsion motor and a frame near the diesel generator. A shaker was mounted on this frame. It causes the strong line at 375 Hz (red line). With regard to the peak positions, the frame spectrum is very similar to the measured spectrum at the diesel generator (black line). The characteristic lines result from the order of firing and come up every 9.5 Hz. In contrast, the peaks in the propulsion motor spectrum (green line) don't appear in the frame spectrum. Further analysis of all measured frames showed, that the diesel generator peaks are generally more dominant than the propulsion motor peaks. The measured spectra change significantly with the ship's speed.

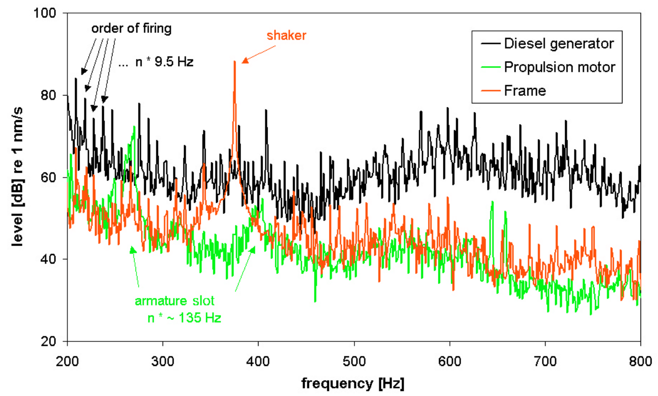

Figure 3: Velocity spectra measured at different points: diesel generator, propulsion motor and a selected frame. The speed of PLANET was about 3 knots.

Radiated Underwater Sound

Acoustical centres can be distinguished using the vertical hydrophone line array as shown in fig. 4. The peaks of the rudder aggregate are assigned to a greater bearing than those

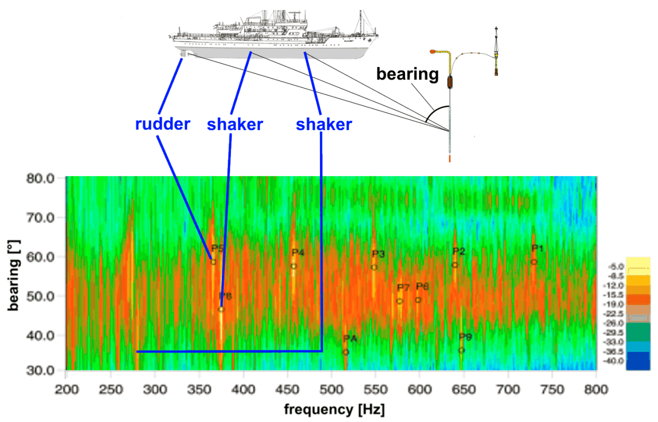

Figure 4: Beam forming with the hydrophone line array. The relative pressure level (dB re 1 10^{-6} Pa) is represented by different colours (from -40 up to 0 dB, s. colour bar). The radiated sound was measured at the same time as the structure borne sound in figure 3.

of the shakers in accordance to the geometrical conditions shown in fig. 4. For the interpretation of the absolute bearing values, the inclination of the array has to be taken into account. This inclination is due to vertical velocity gradients of the water current and the wind, which applies a force on the radio buoy.

The measured spectra are significantly affected by propeller cavitation (s. fig. 5). If the ship passes the buoy at low speed, approximately every 10 s a strong propeller cavitation noise with a characteristic large bandwidth appears (vertical stripes in fig. 5 a). These cavitation stripes are due to the movement of the ship through the swell of the sea. The varying load at the propeller causes more or less cavitation. If the speed is higher than 5 knots, the propeller cavitation is fully developed and is the dominant sound source (fig. 5 b).

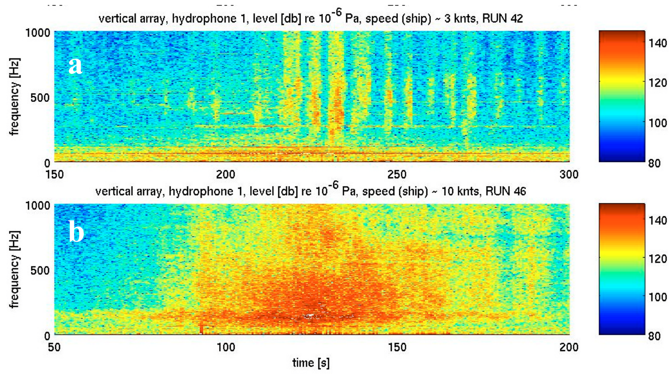

Figure 5: Spectrograms measured by a single hydrophone of the array. The pressure level (dB re 10^{-6} Pa) is represented by different colours. The time intervals are equal for the spectrograms taken at different values of the ship speed: a) ~3 an b) ~10 knots. The CPA was about 50 m at time t ~ 230 s (a) and t ~ 130 s (b).

Further measurements

Generally, the ship structure including the fluid structure interaction seems to be a very selective filter for the sound transfer from the structural sources into the water. In fact, the radiated sound can be analysed very well in comparison with structure borne sound. Right now, profound analysis of coherence, correlation and principal components are carried out in order to describe the relation between structure borne and radiated sound.

Further investigations are planned with our new built research vessel. For a more comprehensive investigation 114 acoustical sensors (accelerometers, microphones and hydrophones) are built in. Cavitation should develop at higher speed than 5 knots. Thus, the investigations can be carried in a wider speed interval.

References

[1] **J. Lighthill:** Waves in Fluids. Cambridge University Press, 1987

[2] **A. Homm, H. Peine:** Schallabstrahlung getauchter Strukturen: Numerische Simulation und Freifeldexperiment. proceedings, DAGA 2000, 720-721