Old Rhine ships must be quiet too

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Summary

All ships traveling on the river Rhine have to comply to the regulations of the Central Commission for the Navigation of the Rhine. These regulations include several demands regarding noise levels inside the ship. Currently, Rhine ships built before 1976 are exempt until 2020 when these ships will have to comply as well.

In 2013 a first study of 4 ships showed that noise levels in these ships are too high. The noise criteria in the bedroom (60 dB(A)) and living room (70 dB(A)) are not met. Over 2500 ships that were built before 1976, are still active. Several trade organizations have warned the Dutch Ministry of Infrastructure and the Environment that the branch will need to invest a lot of money to make their ships less noisy and that this money is not available.

The Dutch Ministry has commissioned the Dutch companies DPA Cauberg-Huygen, Level Acoustics & Vibration and Rubber Design to study the noise more specifically. This new study is not only intended to check the results of the first study but also has the goal to search for affordable noise reducing measures and to see if it is possible in certain situations to deal with the noise regulations in a more flexible way.

For this study noise and vibration measurements have been carried out in five different types of ships. The vibration measurements were used to find the relevant sound sources and noise paths in the ships. Furthermore, a protocol was written for inspectors to easily measure relevant data.

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1. Summary first study (2013)

All ships traveling on the river Rhine have to comply to the regulations of the Central Commission for the Navigation of the Rhine. These regulations include several demands regarding noise levels inside and outside the ship. Currently, Rhine ships built before 1976 are exempt until 2020 when these ships have to comply as well.

Several trade organizations have warned the Dutch Ministry of Infrastructure and the Environment (I&M) that the branch will need to invest a lot of money to make their ships less noisy and that this money is not available. In response to these concerns, I&M commissioned TNO and Level Acoustics in 2013 to study the noise problem [1]. The study had to answer the following questions:

a) Are the current noise regulations necessary and adequately taking into account aspects like health, safety and comfort?
b) What (scientific) motivation is the base for these regulations and is the measurement protocol regarding noise related to the power ratings of the engine, in accordance with the actual use of the power ratings of the ship?
c) How many ships built before 1976 are compliant with the noise regulations? How many are not?
d) Is it possible to take measures to reduce the noise of the ships within the period of time granted to comply with the regulations? What measures have to be taken and how much do they cost?
e) What measures can be taken to come close to the noise levels in the regulations? How much do these measures cost?

In order to answer these questions, literature about the noise regulations has been studied, noise and vibration measurements have been carried out on four ships, the power ratings of a lot of ships have been analyzed, noise reducing measures have been calculated and the costs of the measures have been studied.

The study concludes:

a) The noise regulations for the wheelhouse (70 dB(A)) and engine room (110 dB(A)) are necessary regarding safety and health. The noise regulations for the living room (70 dB(A)) and sleeping room (60 dB(A)) are not sufficient when compared to the noise levels in homes. The noise regulations in a ship allow too much. But, in ships the perception of noise generated by the own ship is different compared to the same noise level in a home. In the literature no evidence was found to back up the thought that the noise regulations should be more severe regarding the aspects of health and comfort. Therefore the present noise regulations are maintained.
b) When a ship is tested for noise, it should travel at 95% of its Maximum Continuous Rating (MCR). This condition is very worst case and almost never met in real life. A new protocol has been suggested (MCR-mix) consisting of a weighted sound level based on a power mix of 85%, 55%, 25% and 5% MCR. The noise levels drop by 2.5 to 5 dB(A) compared to the noise level at 95% MCR.
c) The noise levels on all ships tested are too high in the living room and sleeping room. An exceeding up to 21 dB(A) (sleeping room) has been found. For the wheelhouse and engine rooms the noise levels are in compliance with the noise regulations. It is estimated that over 2.500 ships will have to invest in noise reducing measures.
d) Noise reducing measures are technically possible but too expensive or in conflict with other regulations.
e) Limiting the noise reducing measures to only a box-in-box construction in the living room and/or sleeping room is effective but still too expensive.

2. Second study (2014)

Based on the results from the first study, the Ministry has commissioned the Dutch companies DPA Cauberg-Huygen, Level Acoustics & Vibration and Rubber Design to study the noise problem more specifically. This new study should provide answers to the following questions:

1) If more ships are tested, do the results confirm the findings of the first study?
2) What kind of affordable and practical noise reducing measures are possible, how much reduction is obtained and how much do these measures cost?

3) In what way can we interpret the noise regulations more flexibly
4) What measurement procedure should be used when a more flexible interpretation of the noise regulations is used?

The next chapters answer these questions. The paper concludes with recommendations for the Ministry how to proceed in this dossier.

3. Answers

3.1 Noise levels in ship

In five more ships, noise and vibration measurements have been carried out. The selection of the ships was based on type of ship (different from the first study and five different types in the second study), the age of the ship (build before 1976) and availability during the measurement campaign (October, November 2014 and January 2015). The ships investigated are:

– Melvin (Dortmunder)
– Bobo (pusher tug)
– Kreeft (crane ship)
– Virginia (passenger ship)
– Viator (Rijn-Herne ship)

Due to the constant noise level, a measurement period of 20 seconds was enough in all rooms in order to obtain a stable reading. The L_{Aeq} value was measured both for the overall level and in a 1/3rd octave band spectrum. In order to prevent standing waves from influencing the results, the microphone of the B&K 2250 sound analyzer was slowly moved through the room. In the sleeping room, two measurement locations have been used:

a) In the middle of the room (more or less) and
b) Close to the pillow on the bed to know the sound level in sleeping position.

Both the 95% MCR as well as the MCR-mix haven been measured. Table I shows the results. For every ship the L_{Aeq} is mentioned for all the room types. If more bedrooms have been measured, the highest L_{Aeq} is noted in the table. The noise limits are mentioned in the last row of the table. Sound levels exceeding the noise limits, have been highlighted.

Table I shows that the noise levels are compliant with the limits in the engine room and the wheelhouse. In the living room the noise level exceeds the limit when operating at 95% MCR. When the MCR-mix is used, the noise levels reduce and for three ships the levels are in compliance with the limit. The noise levels in the bedrooms always exceed the limit.

The MCR-mix reduces the sound level by 2 to 8 dB(A).

The results are very similar to the results in the first study.

3.2 Noise levels outside

Not only the noise levels inside the ships have been measured but also the noise level outside of the ship. For the latter, 39 ships (built before 1976) have been measured during the pass by of the measurement location on the banks of the Julianakanaal in the Netherlands. The limit for

Table I. Results sound level ships L_{Aeq} [dB(A)].

ship	*MCR*	*Engine room*	*Wheelhouse*	*Living room*	*Bedroom*
Melvin	85%[1]	109	68	79	80
	Mix	104	62	72	74
Bobo	95%	109	69	74	81
	Mix	105	64	70	76
Kreeft	95%	104	64	73	73
	Mix[2]	-	-	-	-
Virginia	95%	103	51	75	72
	mix	99[3]	48[3]	70	70
Viator	95%	108	60	75	72
	mix	103	56	67	66
Noise Limit		**110**	**70**	**70**	**60**

1: 95% MCR not possible
2: always operating at 95% MCR
3: not all MCR levels could be measured

traveling ships is 75 dB(A) at a distance of 25 meters.
For every ship passing, the 1 second L_{Aeq} has been logged. The highest 1 second L_{Aeq} was used for the calculation of the noise level. Because the distance between the measurement point and the ships was over 30 meters, a calculation had to be made to determine the sound level on 25 meters.

Figure 1 shows the results of the measurement. The x-axis mentions the highest 1 second L_{Aeq}. The y-axis shows the number of ships with that sound level. The sound level between 61 and 65 dB(A) is most common with 56% of the ships. Only one ship reaches the noise limit of 75 dB(A). This ship "sounded" very different from the other ships and it is believed that the exhaust silencer was not working well.

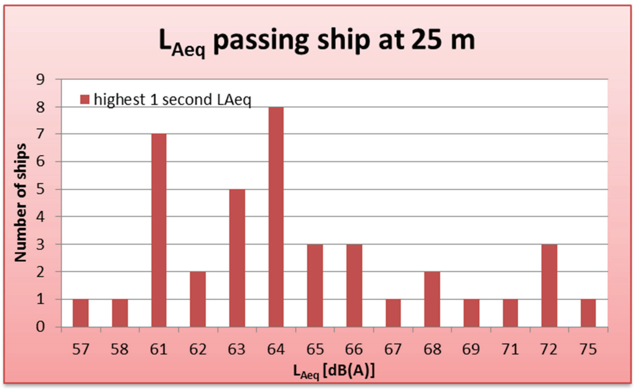

Figure 1: sound levels passing ships

The sound measurements show that the results in the second study (2014) are similar to the results in the first study (2013):

1. Noise reducing measures are necessary to meet the noise limits;
2. The MCR-mix reduces the sound level.

These conclusions confirm the opinion of the shipping branch that the old ships (built before 1976) will have a noise problem once they also have to meet the noise criteria for the (newer) ships built after 1976.

4. Noise reducing measures

4.1 Vibration measurements

In order to determine the relevant noise sources in the ship and subsequently the noise reducing measures, vibration measurements have been carried out using a B&K type 4506 triaxle deltatron accelerometer and a Rion DA-21 4 channel data recorder. All the recorded wav-files have been processed using MatLab. The vibration measurements have been done simultaneously with the noise measurements.

The measurement positions were chosen on the foundation of the engine, on the reversing-clutch, close to the propeller and on walls, ceiling and floor of the living rooms and bedrooms.

The measurement results have been used to determine the relevant noise sources and noise paths. Potential sources are: engine, reversing clutch, propeller and cavitation. Table II gives an overview of the relevant noise sources. They are the same for all ships. Therefore no distinction was made between the ships in table II, only between the rooms. When marked with "XX" the source is the most relevant sound source. All the other potential sources are marked "X".

Table II. noise sources.

room	*engine*	*clutch*	*propeller*	*cavitation*
living	XX	X	X (shaft)	
bed	XX	X	X (shaft and ship skin)	X

Table II shows that the engine is the most relevant noise source. At higher rpm's the reverse-clutch and propeller are also relevant for the overall noise level. Cavitation is often important for the rooms close to the back of the ship which is also close to the propeller. These rooms were the bedrooms in all the studied ships.
A more detailed analysis of the vibration measurements can be found in [2], another paper for Euronoise 2015.
The measurements also showed that the noise path using the ship's construction contributes far more to the sound level in a room than the noise path through the air. This means that noise reducing measures to improve the sound isolation of the engine room or building an enclosure around the engine will not help in reducing the sound level in the bedroom. No, vibration reducing measures have to be taken first.

4.2 Measures

It is obvious that the best way to reduce the sound level is to target the engine. This will affect the sound level in all rooms. But it is also known that this measure is expensive (costs in general more than € 10.000). Since the measures have to be affordable and practical, more measures on the powertrain of the ship (reversing-clutch, propeller) have not been studied in detail because of their substantial additional costs. They are described in a more general way in the report of the 2014 study [3].

Instead, two other types of measures have been chosen:

1. Reducing the sound radiation of walls, floor and ceiling by increasing the mass and influencing the radiation factor (living room, bedroom);
2. Reducing the sound level on a specific spot in the bedroom using anti-noise.

4.3 Engine

The engine should be placed on vibration isolating springs with a resonance frequency of 16 Hz. In order for the springs to work properly, the foundation of the engine should be stiff enough. In most cases this means that the foundation has to be changed. Furthermore all the piping attached to the engine should be vibration isolated as well preventing the vibrations to reach the construction of the ship. These additional actions make this measure rather expensive.
In theory the noise reduction will be about 10 dB(A) but due to the influence of other (mechanical) sound sources the reduction in practice will be limited to about 6-7 dB(A).

During the investigation, the ship *Melvin* was measured twice: first in October 2014 without any noise measure taken and second in January 2015 when the engine was placed on vibration isolators. The noise level in the bedroom dropped by 3 dB(A) and in the living room by 5 dB(A). The influence of the reversing-clutch was rather big thus limiting the overall noise reduction.

4.4 Radiation

Reducing the vibrations of the walls, floor and ceiling in a room will reduce the radiation of noise. The construction of a room is made of rather light materials. Mass should be added to this materials. This can be achieved by gluing an anti-drumming material to the walls, ceiling or floor depending on which area is radiating the most sound.
This measure is reasonably cheap (about € 25/m^2) and will reduce the sound level (in theory) at the most with 6 dB(A). In practice 2 or 3 dB(A) has to be expected.

4.5 Anti-noise in the bedroom

The use of anti-noise is commercially available in headphones, in chairs in airplanes around the head position or in expensive yachts in the bedroom. *Silentium* sells such a system called "Quiet Bubble" which uses an anti-noise system close to the pillow.
This system has been tested with sound recordings made in several ships in the bedroom close to the pillow. Figure 2 shows the result. The blue line shows the spectral sound level before the anti-noise system was switched on. The orange line shows the sound level with the anti-noise system switched on. The anti-noise system reduces the sound level about 6 dB(A). The system is efficient between 80 and 1250 Hz. Of course this reduction is only achieved in the "quiet bubble" around the pillow. It will not reduce the sound level in the entire room.
Once the system is commercially available for freight ships it will probably cost about € 7.000.

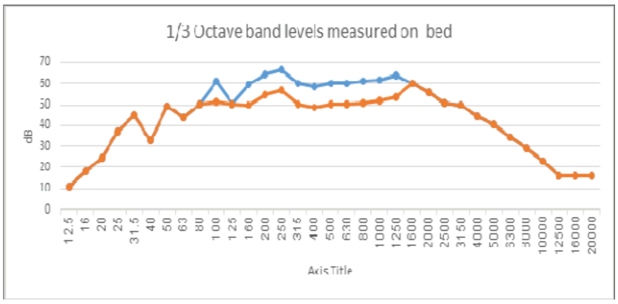

Figure 2: insertion loss for the anti-noise system

4.6 Expedient measures

For the owners of the ship it is not possible to pay for all the technically available measures. This is simply too expensive. They have to make a choice between the money they are able to pay and the noise reduction that those measures will buy. It is expected that a lot of ships will not be able to fulfill the noise limits with affordable measures only. This could mean that a lot of ships will eventually be out of business.

In other fields of noise reduction, for instance traffic noise or industrial noise, the choice of measures is known as well and a procedure is used to determine whether measures are expedient or not. In the industry this is known as ALARA (As Low As Reasonably Achievable). In this study the expediency of the measures has not been worked out but it has been used in answering the question about a more flexible way of using the noise limits.

5. Flexible noise limits

The aspect of flexibility has been worked out for three items:

1. *The use of flexible operating conditions*

The current noise limits are strict: the sound level during an MCR of 95% has always to be less than the limit irrespective the time this noise level is present and despite the fact that most ships hardly ever use 95% MCR. The MCR-mix suggested in the 2013 study and used in the 2014 study corresponds with a realistic use of the MCR operations.

2. *The use of an averaged sound level including quiet time periods instead of an instantaneous sound level*

In modern noise regulation not only the sound level is of importance, but also the duration of the sound level. In European noise regulations the L_{den} is used, an averaged noise level over a year. Another example is the regulation about noise on the working place: the averaged noise level over 8 hours has to be within the limit. Both regulations allow time with noise levels above the noise limit due to the averaging in time.
This averaging could be used when evaluating the noise level in a ship. For instance if a ship travels 1 hour during the night (23.00 till 07.00 o'clock) and is anchored for the rest of the night, the averaged sound level over the night would be:

$L_{Aeq(1\ hour)} - 10 * \log(1\ hour / 8\ hours)$

If the L_{Aeq} during the hour of traveling is 68 dB(A) in the bedroom (8 dB(A) above the limit) the averaged sound level over the night will be 68 – 9 = 59 dB(A). This is within the limit.

3. *The use of exemption if all reasonably measures have been taken*

This method refers to European regulations about traffic noise. It uses two kinds of limits:

a) Preferred limit: this is the sound level you have to try to achieve;
b) maximum limit: this is the sound level you cannot exceed.

If the measured sound level (measured according the MCR-mix and including averaging in time), exceeds the maximum limit, noise reducing measures have to be taken. Those measures have to be expedient.
If the measures reduce the sound level below the preferred limit, those measures have to be taken even if they reduce the noise more than necessary.
If the measures reduce the sound level below the maximum limit but above the preferred limit, it is still possible to get a certificate for the ship as long as all expedient measures have been taken.
When the measured sound level already meets the preferred limit, no additional measures have to be taken even if they are expedient.

6. Protocol

The MCR-mix requires a new measurement protocol because more operating situations have to be measured. It is not always necessary to measure all the power ratings. When just checking the sound level, it is enough to measure the power ratings starting with 85% and 55%. The MCR-mix sound level is calculated and evaluated. If it meets the criteria, the measurement can stop. If it doesn't, the next MCR% has to be measured and the MCR-mix sound level recalculated and re-evaluated.
When the objective of the measurement is to be able to tell what noise reducing measures should be taken, all MCR% have to be measured.
In order to help the inspector or consultant with the calculation of the MCR-mix sound level, a digital spreadsheet was set up.

7. Recommendations

The 2014 study confirms the conclusions of the 2013 study: if the 2020 noise limits are strictly applied, a lot of old ships (built before 1976) will eventually be out of business because they cannot afford the needed noise reducing measures.
The study presents several solutions for this problem but not all solutions have already been worked out completely. Therefor it is recommended:

1. To introduce the results of the study to the CCR and to make sure the flexible noise level is put on the agenda.
2. To study the criteria about the expediency of the noise reducing measures.

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