

Noise Reduction in Ship Engine Room by Optimisation of Muffler Design

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Abstract—noise level onboard, particularly in the engine room, requires a careful monitor to not causing any disruption or discomfort to the shipboard environment. For monitoring purposes, an appropriate alternative system can be applied if the noise level exceeds the limit set by applicable regulations such as IMO, ABS, and LR. The current research uses computational methods to map noise contours in the engine room and recommends some muffler models to reduce the noise level in the MV Natuna Express engine room. Based on the field measurement, the noise level exceeds the Standards value at a maximum of 110 dB. Mapping and designing of the muffler models were based on the measurement data. Simulation results show that greater transmission loss hence noise reduction is affected significantly by the expansion of muffler chamber length and diameter. Modification of the muffler chamber using plywood and the tailpipe on both ME ON Generator ON and ME OFF Generator ON conditions respectively reduce the noise approximately by 24.94 dB and 10.50 dB.

Keywords—engine room, muffler design, ship noise, transmission loss.

I. INTRODUCTION

Noise is a problem that is quite important, especially concerning the comfort of the engine room on the ship. The biggest source of noise in the ship is in the engine room. Examples of noise that directly affect the comfort of the crew and all passengers, among others, come from the main engine room itself, which is the largest source of noise, then there are exhaust gas outlets on the deck as well as auxiliary machinery and others.

Previous research stated that the crew of the Jaya Niaga vessel experienced complaints because the noise in the engine room was 120 dB, and the IMO standard was 120 dB [1]. To reduce noise, it is necessary to understand the source characteristics of noise, how to propagate to the entire body of the ship, and how to effectively and economically reduce it. With that, it is necessary to reduce noise by using a muffler or exhaust gas in the main engine room, so that the sound obtained becomes a healthy environment. There was also a past study stated that the noise level in KMP. Dharma Rucitra is under predetermined standards that do not exceed 102 dB and produce a contour pattern that clearly shows the components that have the highest and lowest noise levels. The study produced a contour pattern that clearly shows the components that have the highest and lowest noise levels and outlined a method to reduce the noise efficiently by redesigning the muffler [2]. Whereas in other studies, it was stated that the recommended noise level standard for crew cabins based on IMO recommendations is 60 dB while the measured noise level is 70,78 dB at points 9 and 70,16 dB at point 10

and recommended mufflers to reduce noise efficiently and optimally [3]. A study on noise reduction disclosed that plywood is well used as a noise controller because plywood has a large mass so that it has a high enough transmission loss (TL) and can reduce vibration propagation. Another material, such as foam and fiber layer, is said to be ineffective due to its low mass and density [4]. An alternative system using plywood as a barrier is proclaimed to be more efficient and possesses the highest TL as compared to other alternative systems [5].

The current research estimates the noise level of the main engine (ME) when the vessel is in ME ON Generator ON and ME OFF Generator ON conditions via field measurement test and noise mapping method. The current Muffler near the engine and tailpipe were modeled and modified to effectively reduce the noise in the engine room. Recommendations were made based on the most optimum muffler model and configurations.

II. METHOD

A. Noise measurement

The main source of noise on board MV Natuna Express is originated from two main engines and two generators, respectively of 500 kW and 50 kW as shown in Figure 1. The port side engine is identified as ME 1, whilst the starboard one is referred to as ME 2. At full speed, the engine speed is respectively 1160 rpm and 1200 rpm.

A field test to measure the noise level due to the operation of the engines and generators in the engine room was executed at the point defined by the Standards [6], as illustrated in Figure 2. Following the point, the sound level meter was placed 1 m above the floor whilst the minimum distance to the equipment to be measured, or the wall is approximately 0,5 cm. During measurement, ME 1 and ME 2 are respectively set at 110 RPM and 145 RPM.

B. Reliability Check and Error Analysis

Reliability determines the accuracy and precision of a measurement procedure. A reliable instrument measures the desired values hence contribute to testing validity.

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Figure 1. Main engine (left) and generator set (right) of MV Natuna Express

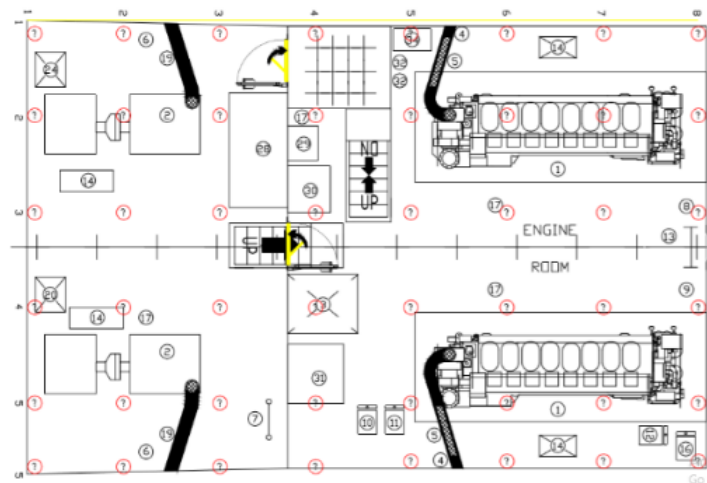


Figure 2. Noise measurement point for engine room

One of the reliability aspects viz. stability concerns with securing consistent results thru repeated measurement using the same measuring instrument and procedure [7]

In the current study, each measurement of noise level was repeated three times. The noise level was measured at the main engine, generator, and other components operating simultaneously during sailing and anchoring correspond to ME ON Generator ON and ME OFF Generator ON conditions. In the earlier condition, both main engines and generator sets were run whilst in the latter, only the generator set was operated.

The stability, precision, and accuracy of the measurement result were examined via error analysis employing two important values, namely, mean (\bar{X}) and standard error/deviation (σ). The former, which refers to

the average of the measured data, reflects the accuracy of the measurement result. Meanwhile, the latter, which denotes the spread of the measured values against the mean, indicates the precision of the data obtained [8].

The study employed an error of 3σ . This implies that the difference in the measured data is significant if the values $\geq 3\sigma$ and insignificant if otherwise. Correspondingly, the confidence limit is $\pm 3\sigma$, which corresponds to a 99.73% confidence level.

C. Modeling of Existing Muffler

The study intended to alternate the existing Muffler into a more efficient design. Modeling of the existing design as initial reference was based on several parameters tabulated in Table 1. Figure 3 displays the

TABLE 1.
MUFFLER MODELING PARAMETERS

No	Parameter	Remarks
1	Frequency	The frequency used is the frequency of the Main Engine with a range of 30-1850 Hz
2	Length of Expansion space	Length of space expansion on Muffler
3	Expansion Space Diameter	The diameter of expansion chamber tube on Muffler
4	Diameter of Inlet and Outlet Pipes	Inlet and outlet pipe diameter on Muffler
5	Inlet Pipe Length	The length of the inlet pipe on the Muffler
6	Outlet Pipe Length	The length of the inlet pipe on the Muffler

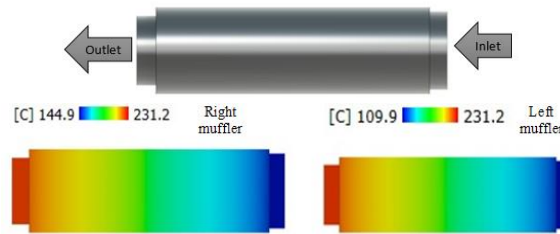


Figure 3. Existing muffler (up) and the model (down)

existing Muffler and the 3D model produced using the computational method.

D. Engine Room Noise Mapping

Noise mapping was carried out based on the measured noise data obtained previously. The study employed a computational method for mapping the noise. This initial noise mapping represents the noise produced by the current engine room machinery systems before any modifications, particularly on the Muffler.

E. Remodeling of Existing Muffler

Modification of the existing Muffler was performed to

both mufflers near the main engine and tailpipe. Four alternative models, referred to as R₁, R₂, R₃, and R₄, were designed to investigate the optimum dimension in reducing the noise. Two parameters of expansion room length and diameter were chosen as the variable of the remodeling. Table 2 contrasts the dimension of the Muffler alternative designs against the original model, whilst Table 3 correspondingly displays the designs. For R indicated the right side where the Muffler placed in the engine room, the left side muffler was coded as L. Hence, the four left side mufflers were identified as L₁, L₂, L₃, and L₄.

TABLE 2.
MODIFIED MUFFLER DIMENSIONS

Parameter	Muffler dimension				
	Existing	R ₁	R ₂	R ₃	R ₄
Expansion Room Length (cm)	310 cm	300 cm	320 cm	320 cm	310 cm
Expansion Room Diameter (cm)	98 cm	88 cm	110 cm	98 cm	110 cm
Intel Pipe Diameter	78 cm				
Inlet Pipe Length	22 cm				
The Diameter of Outlet Pipe	88 cm				
Outlet Pipe Length	20 cm				
Pipe Thickness	0.5 cm				

TABLE 3.
MUFFLER ALTERNATIVE DESIGNS

Recommended Muffler			
Muffler Code	Right Muffler	Muffler Code	Left Muffler
R ₁	[C] 145 [C] 230.5	L ₁	[C] 110 [C] 230.5
R ₂	[C] 144.9 [C] 230.7	L ₂	[C] 109.9 [C] 230.7
R ₃	[C] 144.9 [C] 232	L ₃	[C] 109.9 [C] 231.5
R ₄	[C] 144.7 [C] 230	L ₄	[C] 109.6 [C] 230

F. Computation of Transmission Loss

The most optimum muffler design was determined based on the maximum TL value. Manual computation of the value was obtained by using the Plane Wave Assumption given by

$$TL = 10 \text{Log}[1 + ((m^2 - 1)/(2m \sin kl)^2)] \quad (1)$$

where

- m : Comparison of the cross-sectional area of space expansion and inlet/outlet pipes
- l : Length of the expansion space
- k : wavenumber

formulated as

$$k = 2 \pi \text{freq/speed of sound} \quad (2)$$

Simultaneously, the TL value was generated via CFD simulation.

G. Remapping of Engine Room Noise

As the most optimum muffler design identified, the engine room noise was remapped employing the selected design. Remapping was executed on both conditions of ME ON Generator ON and ME OFF Generator ON. Analysis of the noise level prior to and after modification of the Muffler near the main engine and tailpipe was carried out accordingly.

III. RESULTS AND DISCUSSION

A. Accuracy of Measurement Data

The accuracy of the measured noise level in the engine room of MV Natuna Express during ME ON Generator ON and ME OFF Generator ON representing sailing and anchoring conditions are as shown in Table 4. As seen in the table, all measured data for both conditions satisfy the three standard deviations (3σ) limits. By adopting the statistical criteria defined, a satisfaction of the limit implies that the study is 99,73 % confident that all measured noise data are accurate to the stated degree [6] hence reliable for further use throughout the study.

TABLE 4.
 ACCURACY OF NOISE LEVEL DATA ON ME ON GENERATOR ON (LEFT) AND ME OFF GENERATOR ON (RIGHT) CONDITIONS

R (x, y)		Noise Level			σ	X-3σ	X+3σ	Satisfy	R (x, y)		Noise Level			σ	X-3σ	X+3σ	Satisfy
x	Y	X ₁	X ₂	X ₃					x	Y	X ₁	X ₂	X ₃				
0	0	117,7	117,4	117,4	0,173	116,98	118,02	✓	0	0	102,1	102,2	102,3	0,100	101,90	102,50	✓
	1	117,7	117,9	117,9	0,115	117,49	118,18			1	102,6	102,2	102,1	0,265	101,51	103,09	
	2	115,7	115,6	115,1	0,321	114,50	116,43			2	103,3	103,6	103,6	0,173	102,98	104,02	
	3	116,2	116,5	116,7	0,252	115,71	117,22			3	107,2	107,1	107,3	0,100	106,90	107,50	
1	4	117,5	116,6	117,2	0,458	116,98	118,47	✓	4	107,1	107,7	106,9	0,416	105,98	108,48	✓	
	0	117,2	117,7	117,5	0,252	116,71	118,22		0	106	110	110,2	2,369	101,63	115,84		
	1	117,7	117,4	117,4	0,173	116,98	118,02		1	105	107	107	1,155	102,87	109,80		
	2	113,2	112,6	112,2	0,503	111,16	114,18		2	108	108	110	1,155	105,20	112,13		
2	3	114,2	114,3	115	0,436	113,19	115,81	✓	3	108,1	108,2	107,8	0,208	107,41	108,66	✓	
	4	115,6	116,2	115,2	0,503	114,16	117,18		4	107,2	106,7	106,5	0,361	105,72	107,88		
	0	116,3	117,9	118,5	1,137	114,15	120,98		0	101,2	101,3	101,3	0,058	101,09	101,44		
	1	118	117,4	117,3	0,379	116,43	118,70		1	98,8	98,8	98,7	0,058	98,59	98,94		
3	2	114,5	114,1	113,8	0,351	113,08	115,19	✓	2	94,2	94,1	100,1	3,436	85,83	106,44	✓	
	3	112,8	113,1	113,4	0,300	112,20	114,00		3	105,5	105,5	105,3	0,115	105,09	105,78		
	4	118,3	116	116,7	1,179	113,46	120,54		4	108	107,8	107,7	0,361	105,72	107,88		
	0	115	113,5	115	0,866	111,90	117,10		0	101,7	101,6	102,1	0,265	101,01	102,59		
4	1	113,5	113,9	113,5	0,231	112,94	114,33	✓	1	94,5	94,6	100,1	3,205	86,79	106,01	✓	
	2	112,1	111,8	111,5	0,300	110,90	112,70		2	94,2	94,6	100,1	3,297	86,41	106,19		
	3	113,9	114,9	115	0,608	112,78	116,42		3	101,5	101,8	102,9	0,737	99,86	104,28		
	4	117,1	116	117	0,608	114,88	118,52		4	104,8	105,1	104,8	0,173	104,38	105,42		
5	0	115,5	115,3	115,2	0,153	114,88	115,79	✓	0	97,6	97,7	97,5	0,100	97,30	97,90	✓	
	1	114,2	115,3	115	0,569	113,13	116,54		1	90,6	90,4	90,5	0,100	90,20	90,80		
	2	113,1	113	113,2	0,100	112,80	113,40		2	88,8	88,5	88,8	0,173	88,18	89,22		
	3	114,1	114,2	114	0,100	113,80	114,40		3	94,4	94,3	93,8	0,321	93,20	95,13		
6	4	115	114,6	115,2	0,306	114,02	115,85	✓	4	96,5	96,2	96,4	0,153	95,91	96,82	✓	
	0	114,3	114,9	116,8	1,305	111,42	119,25		0	98,6	97,8	98,3	0,404	97,02	99,45		
	1	114,3	114,5	114,5	0,115	114,09	114,78		1	90,8	90,7	90,6	0,100	90,40	91,00		
	2	114,7	114,1	114,5	0,306	113,52	115,35		2	89,1	89,2	89,1	0,058	88,96	89,31		
6	3	114,1	113,7	113,8	0,208	113,24	114,49	✓	3	91,8	91,2	91,5	0,300	90,60	92,40	✓	
	4	115,3	115,1	115,3	0,115	114,89	115,58		4	95,3	94	94,2	0,700	92,40	96,60		
	0	117,7	116,8	117,7	0,520	115,84	118,96		0	101,4	101	101,6	0,306	100,42	102,25		
	1	115,6	116,4	115,7	0,436	114,59	117,21		1	93	92,5	92,5	0,289	91,80	93,53		
6	2	116,7	116,4	116,9	0,252	115,91	117,42	✓	2	89,7	89,6	89,7	0,058	89,49	89,84	✓	
	3	115,3	115,5	115	0,252	114,51	116,02		3	96,3	96,4	96	0,208	95,61	96,86		
	4	116,4	116,5	117	0,321	115,67	117,60		4	100,7	101	101	0,173	100,38	101,42		

TABLE 5.
 TRANSMISSION LOSSES OF VARIOUS MUFFLER DESIGNS

Parameter	Muffler dimension				
	Existing	R ₁	R ₂	R ₃	R ₄
Expansion Room Length (cm)	310 cm	300 cm	320 cm	320 cm	310 cm
Expansion Room Diameter (cm)	98 cm	88 cm	110 cm	98 cm	110 cm
Temperature Speed Not Full	110 C				
Full Speed Temperature	230 C				
Full Speed Round	1160 rpm				
Transmission Loss	24,78 dB	24,65 dB	24,94 dB	24,92 dB	24,74 dB

B. Recommended Muffler Model

The most efficient muffler design was determined based on the maximum TL value. Table 5 displays the TL values of the existing, and the four modified mufflers vary in length and diameter of the expansion room. As shown in the table, muffler R₂ possessing a bigger expansion room in both length and diameter, respectively, by 3,23 % and 12,24 % of the existing design, generates the highest TL value by 24.94 dB, which equals to 0,65 % of the existing TL value.

The presented values signify that a bigger expansion room by length is more efficient than the diameter. As evidence, muffler R₃ possessing only a 3,23 % longer expansion room, yielded a higher TL value by 0,73 % as compared to muffler R₄, which has an even bigger diameter by as much as 12,24 % from an existing design. The earlier design increases the TL value by 0,65 %, whilst the latter, unfortunately, decreases the value by 0,16 %. Various TL values shown by each design conform with suggestions from previous research who denoted that type and shape of the Muffler and the barrier affect the efficiency of the system indicated by the TL values [5].

C. Engine Room Noise Contour

Noise mapping has been executed at two conditions of prior and after modification of the Muffler. At the initial condition prior to system modification, noise contour was yielded from the mapping of the measured noise

level. After modification, the contour was generated from the mapping of the modified noise level obtained from the computation of the measured noise level against the TL due to the system modification.

1) Initial Noise Contour

Figure 4 displays the current engine room noise contour on both ME ON Generator ON and ME OFF Generator ON conditions.

On the ME ON Generator ON condition, there is only one generator set, which is the right generator (1). ME 1 and ME 2 has a circular noise distribution because it is assumed that the noise distribution is evenly distributed. In the engine room, it is calculated from the coordinates (x, y) = (4.1) to (7.5) using the calculation of 3 sources, namely 2 ME ON and 1 ON generator set number 1. The red color to the organism is around the right generator set because it is a source of noise that was around the right generator set is measured 10 cm from the generator, and the result is 117.8 dB.

The Main engine has an orange color because the engine room has a range of 116 - 114.2 dB. This is because, in the engine room, there are several windows (Shuttle side) and open manhole positions that are at coordinates (x, y) = (7.3). Overall the engine room has an average noise level of 111 to 117 dB. Overall the engine room is not following the IMO standard where the engine

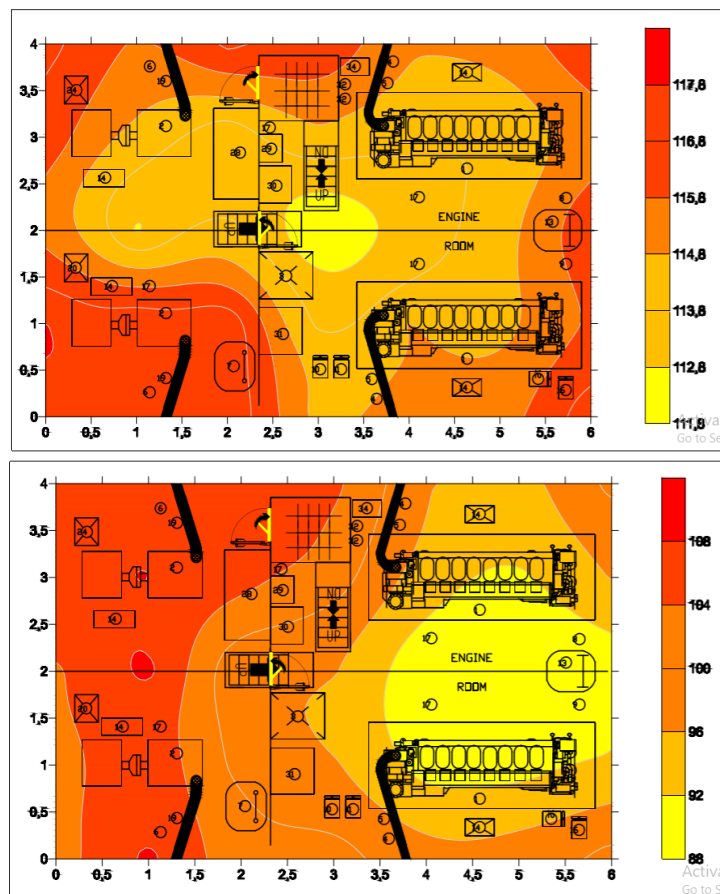


Figure. 4. Current noise contour on ME ON Generator ON (up) and ME OFF Generator ON (down) conditions

room for noise limits is 110 dB while the conditions in the field for noise limits are above 111 dB.

On ME OFF Generator ON condition, only one generator set is on the left (1) generator set. The solid red color is found around the left generator because it is a source of noise where around the left generator is measured 10 cm from the generator, and the result is 108 dB. The main engine has a yellow range with a noise range of 88 - 92 dB. This is because the condition of the Main engine is off, and in the engine room, there are several windows (Shuttle side) and open position manholes that are at coordinates $(x, y) = (7.3)$. So that the noise only comes from the sound of the right generator. Overall engine room noise is following the IMO standard if the state of the Main engine OFF and Generator is ON and where for the engine room for noise limits is 110 dB based on the International standard while the conditions in the field for noise limits are a maximum of 108.7 dB.

2) Noise Contour of Modified System

Figure 5 and Figure 6 respectively depict the engine room noise contour due to the modification of the Muffler near the main engine and near the tailpipe on both ME ON Generator ON and ME OFF Generator ON conditions.

As seen from Figure 5 on the ME ON Generator ON condition, there is only one generator set, which is the right generator (1)—in the engine room, calculated from the coordinates $(x, y) = (4.1)$ to (7.5) using the calculation of 3 sources, namely 2 ME ON and one generator set ON.

The red color to orange is found around the right generator set because it is a source of noise where around the right generator set is measured 10 cm from the generator, and the result is 92.9 dB. The main engine has a red color to the organizer because, in the engine room, it has a range of 86.9 - 92.5 dB after modifying the Muffler on the Main engine. This is because, in the engine room, there are several windows (Shuttle side) and open manhole positions that are at coordinates $(x, y) = (7.3)$ after modifying the Muffler on the Main engine for the overall noise in the engine room according to the IMO standard where the engine room for noise limit is 110 dB while the conditions in the field for noise limits are below 92.9 dB.

Correspondingly, on ME OFF Generator ON condition, only one generator set is on the left (1) generator set. The concentrated orange color is found around the left generator set because it is a source of noise where around the left generator is measured 10 cm from the generator, and the result is 83.1 dB. The main engine has a color to

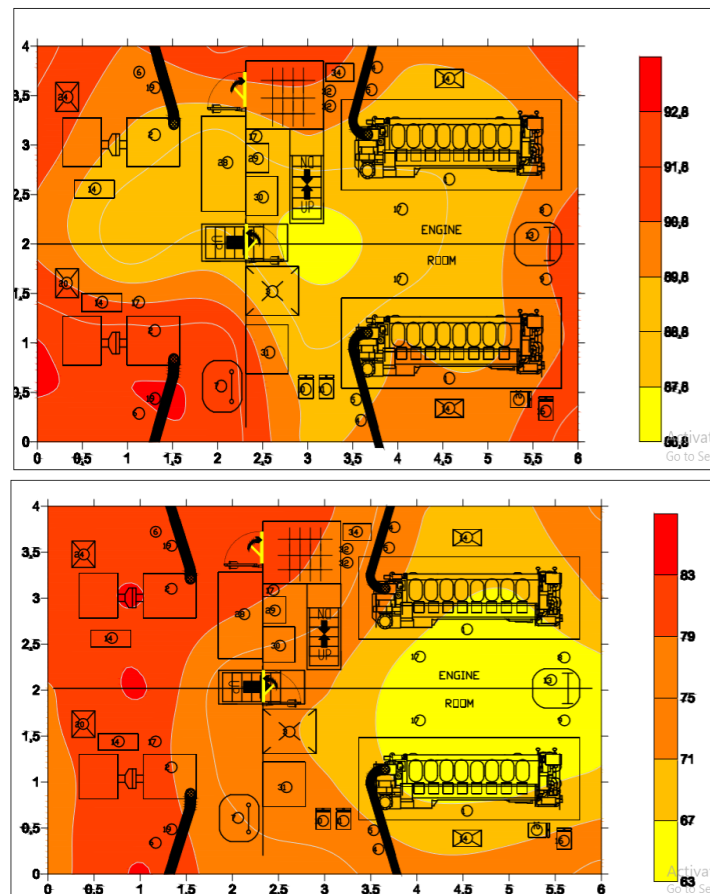


Figure 5. Noise contour with muffler modification near main engine on ME ON Generator ON (up) and ME OFF Generator ON (down) conditions

ORENEN with a range of noise of 63.8 - 80 dB. after modifying the Muffler on the Main engine. This is because, in the engine room, there are several windows (Shuttle side) and open manhole positions that are at coordinates $(x, y) = (7.3)$ after modifying the Muffler on the Main engine for the overall noise in the engine room according to the IMO standard where for the engine room for noise limit is 110 dB while the conditions in the field for noise limits are below 83.8 dB.

In Figure 6 on the ME ON Generator ON condition, it was shown that there is only one generator set, which is the right generator (1). ME 1 and ME 2 has a circular noise spread because it is assumed that the spread of noise is even. In the engine room, it is calculated from the coordinates $(x, y) = (4.1)$ to (7.5) using the calculation of 3 sources, namely 2 ME ON and one generator set ON. Air density also affects noise velocity. In the morning conditions, the air is cold and quickly delivers noise.

Main engines 1 and 2 have the same noise level because of the same RPM. But the engine 1 has a slightly higher noise level because the engine works harder than the Main engine 2. The red color of the engine is around the right generator because it is a source of noise, which is around 10 cm from the generator, and the result is

amounting to 107.1 dB. The highest noise value among all noise values due to high rotation and the sound produced is also very noisy. The Main engine has the color of the original because, in the engine room, it has a range of 101.3 - 107.3 dB after experiencing a modified Muffler on a Tail Pipe. This is because, in the engine room, there are several windows (Shuttle side) and open manhole positions that are at coordinates $(x, y) = (7.3)$. Spread on coordinates $(6,2)$ as in the picture because the calculation uses three sources and has different results a little far from the measurement results in that point so that the contour results obtained are like that. After modifying the Muffler on the Main engine for the overall noise in the engine room according to the IMO standard, the engine room for noise conditions is 110 dB, while the conditions in the field for noise limits are below 107.3 dB.

From the same figure on ME OFF Generator ON condition, it was also shown that only one generator set is on the left (1) generator set. Orange red-orange color is found around the left generator set because it is a source of noise where around the left generator is measured 10 cm from the generator, and the result is 97.5 dB. The highest noise value among all noise values due to high rotation and the sound produced is also very

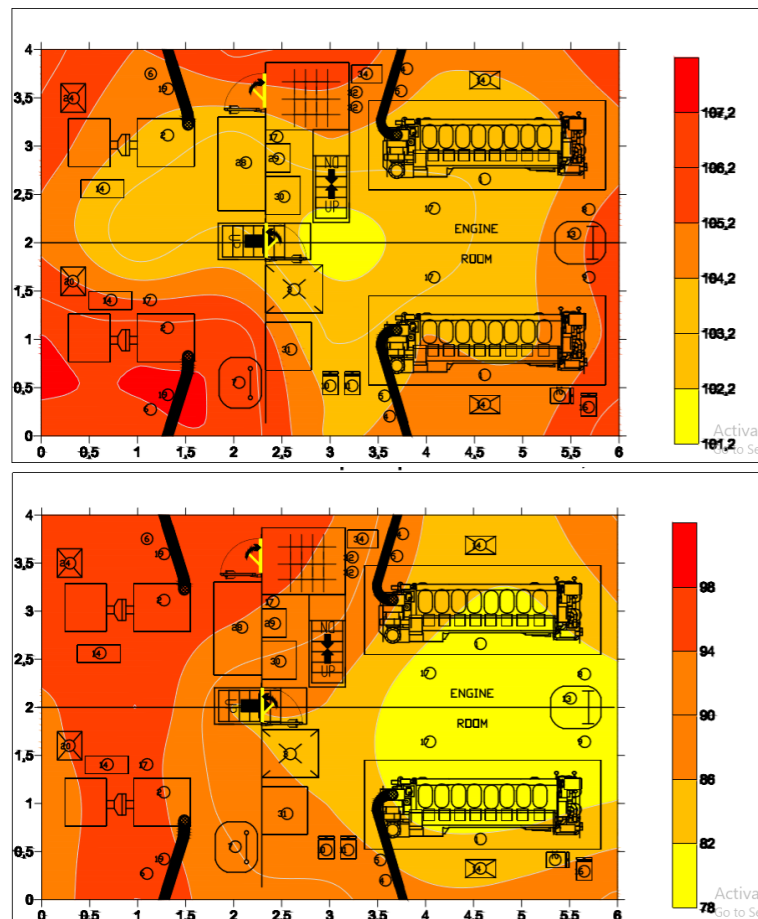


Figure. 6. Noise contour with muffler modification near tail pipe on ME ON Generator ON (up) and ME OFF Generator ON (down) conditions

noisy. The main engine was colored in orange with a range of noise of 78.2 - 82.2 dB. after experiencing a modification of the Muffler on a Tail Pipe. This is because, in the engine room, there are several windows (Shuttle side) and open manhole positions that are at coordinates (x, y) = (7.3).

ME 1 and ME 2 has a circular noise spread because it is assumed that the spread of noise is even. Noise contours form like ocean waves, which are following the nature of noise that is propagated through the air so that the spread is widespread and even. Air density also affects noise velocity. In the morning conditions, the air is cold and quickly delivers noise after modifying the Main engine Muffler for the overall noise in the engine room according to the IMO standard, where the engine room for noise is 110 dB while the conditions in the field for noise limits are below 98.2 dB.

D. Effect of Muffler Modification on Noise Level

The noise level of the currently installed machinery system obtained from the point by point measurement on ME ON Generator ON and ME OFF Generator ON conditions was analyzed against the ones from the modified system installing the recommended Muffler as shown in Table 6. Table 7 correspondingly summarised the values prior to and after the modification of the Muffler both near the main engine and tailpipe. Three values comprise maximum, minimum, and average, which were presented for reference.

As seen from the summary in the table, the noise level on both ME ON Generator ON and ME OFF Generator ON conditions decrease after installation of the modified Muffler. The reduction respectively values approximately 21,6 % and 25,0 %. The numbers signify that it was easier to downgrade the noise during engine off condition. As a matter of fact, it is reducing the noise of a system having a 500 kW engine and 50 kW generator which on certainly a lot harder than handling another system merely running the 50 kW generator

TABLE 6.
 NOISE LEVEL ON ME ON GENERATOR ON (LEFT) AND ME OFF GENERATOR ON (RIGHT) CONDITIONS

R(x,y)		Current noise level	Noise level after muffler modification	R(x,y)		Current noise level	Noise level after muffler modification
x	Y			x	Y		
0	0	117,5	92,6	0	0	102,2	77,3
	1	117,8	92,9		1	102,3	77,4
	2	115,5	90,5		2	103,5	78,6
	3	116,5	91,5		3	107,2	82,3
	4	117,1	92,2		4	107,2	82,3
1	0	117,5	92,5	1	0	108,7	83,8
	1	117,5	92,6		1	106,3	81,4
	2	112,7	87,7		2	108,7	83,7
	3	114,5	89,6		3	108	83,1
	4	115,7	90,7		4	106,8	81,9
2	0	117,6	92,6	2	0	101,3	76,3
	1	117,6	92,6		1	98,8	73,8
	2	114,1	89,2		2	96,1	71,2
	3	113,1	88,2		3	105,4	80,5
	4	117	92,1		4	107,8	82,9
3	0	114,5	89,6	3	0	101,8	76,9
	1	113,6	88,7		1	96,4	71,5
	2	111,8	86,9		2	96,3	71,4
	3	114,6	89,7		3	102,1	77,1
	4	116,7	91,8		4	104,9	80
4	0	115,3	90,4	4	0	97,6	72,7
	1	115,3	89,9		1	90,5	65,6
	2	113,1	88,2		2	88,7	63,8
	3	114,1	89,2		3	94,2	69,2
	4	114,1	90		4	96,4	71,4
5	0	115,3	90,4	5	0	98,2	73,3
	1	115,3	89,5		1	90,7	65,8
	2	114,4	89,5		2	89,1	64,2
	3	113,9	88,9		3	91,5	66,6
	4	115,2	90,3		4	94,5	69,6
6	0	117,4	92,5	6	0	101,3	76,4
	1	115,9	91		1	92,7	67,7
	2	116,7	91,7		2	89,7	64,7
	3	115,3	90,3		3	96,2	71,3
	4	116,6	91,7		4	100,9	76

TABLE 7.
 NOISE LEVEL PRIOR AND AFTER SYSTEM MODIFICATION

Condition	Existing System		Modified System	
	Near Main Engine (dB)		Near Main Engine (dB)	Near Tail Pipe (dB)
ME ON Generator ON	Min	: 117,8	Min	: 92,9
	Max	: 112,7	Max	: 88,2
	Average	: 115,4	Average	: 90,5
ME OFF Generator ON	Min	: 108,7	Min	: 83,8
	Max	: 89,2	Max	: 63,8
	Average	: 99,5	Average	: 74,6

using the same modified Muffler.

Highlights of the muffler modification on the noise level were given as follows.

- 1) Modification of the Muffler on the main engine using an alternative barrier of plywood material could produce a transmission loss of as much as 24,94 dB and decreased the current system possessing 117,8 dB noise level to the very least of 92,9 dB. Plywood is a material that can reduce the best noise among others with modifications to the expansion space, which initially 310 cm to 320 cm, and modify the diameter of the expansion chamber, which was initially 98 to 110 cm. Where the first Transmission Loss can reduce noise by 24,727, after modification, it can reduce up to 24,94 dB. And there is a change in contour noise mapping when compared to Existing conditions. The greater the modification, the greater the Transmission Loss generated to reduce noise on the Muffler.
- 2) When the ship is in Main engine OFF, and the ON Generator can also reduce noise up to 24,94 dB. Where noise reaches 108,7 dB, then modifying the Muffler on the Main engine with Plywood material can reduce noise to 83,8 dB. For the Muffler parameters themselves, everything is the same. The only difference is the condition of the ship. But for noise mapping contours, there are differences with the condition of Main engine ON and Generator ON. For contour noise, there are differences when compared to Existing conditions.
- 3) Then for the Muffler placed on the tailpipe, it produces the biggest noise 107,3 dB. When modifying this Tail Pipe, noise can be reduced to 10,507 dB. The condition of the ship when the Main engine ON and ON generator where after the modified condition produces noise up to 107,3 dB where previously the noise reaches 117,8 dB and when the vessel is in the main engine OFF and Generator ON, where the biggest noise is 98.2 dB previously 108,7 dB. For contour noise, there are differences when compared to Existing conditions.

E. Noise Level based on the Standards

Table 8 shows the compliance of the noise level prior to and after the modification of the Muffler against three Standards criteria comprise IMO, LR, and ABS. As seen from the table, the measured noise level of the existing machinery system onboard MV Natuna Express exceeds the Standards thresholds. After modification of the Muffler on the system, the noise level drops quite far

below the threshold values. This signifies that the modified Muffler functions effectively as expected and efficiently reduced the noise in the existing machinery system.

Violation of the current system noise level to the Standards value might be due to several factors, including:

- 1) In the engine room, excessive noise can occur due to damping conditions that are not feasible.
- 2) Narrow and open engine room, so that the sound source not only comes from the engine room but also from outside sounds such as wind speed or passenger noise on the passenger deck because of the open windows and doors in the engine room.
- 3) The silencer of Muffler's exhaust gas main engine is not feasible and thinning.

IV. CONCLUSION

Based on the finding of the study, it was deduced that

- 1) The noise condition of the Natuna Express Passenger High-Speed Express on the Gresik shipping channel - Bawean has a noise source, namely two main engine sets of ships and two generator sets with the Main engine ON conditions having an average noise of 115,4 dB and Generator ON when sailing and Main engine OFF and Generator ON when anchored have an average noise of 99,5 dB. Even though the International standards for noise in the Engine Room such as IMO, LR, and ABS are 110 and 100 (ABS), with the results of the noise, it should not be allowed because it will disturb the noise of the crew of the ship because it is below the prescribed standard.
- 2) After making a recommendation on the Muffler modeling near the Main engine and near the Tail Pipe, it produces an efficient Muffler recommendation to reduce Transmission Loss. Where in figure R3 and L3 can reduce noise by 24,94 dB for Muffler near the Main engine, while for Muffler near the tailpipe can reduce by 10,507 dB.
- 3) The modification of Muffler using Barrier with Plywood material: where the parameters used are only the length of the expansion space and the diameter of the expansion chamber. Where modification of the length of the expansion space is 310 to 320 cm, and the diameter of the expansion chamber is 98 to 110 cm and produces a Transmission Loss of 24,727 dB to 24,94 Pipe resulting in a Transmission Loss of 10,507 dB.

TABLE 8.
NOISE LEVEL COMPLIANCE CHECK

Average noise level		The Standards threshold value		
Existing system (dB)	Modified system (dB)	IMO (dB)	LR (dB)	ABS (dB)
115,4	90,5	110	110	100

With data as dB because of the longer and bigger the diameter in the barrier, the greater the Transmission Loss to reduce noise.

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