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Evaluation Effect of Noise and Vibrations on Railway Passenger

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Abstract: *The ride comfort is one of the most important rail vehicle assessment standards. The ride comfort is given by several different adverse effects which passengers are subject on. Noise and vibrations have an important influence on a passenger's perception of vehicle quality and cabin interior noise levels are a key criteria. The measurement are performed in two conditions, static to measure background noise and dynamic measurement at maximum speed . The results show that, the measured noise in the cabin is at the level that is permissible according to Regulation of the Minister of Health No. 70 (2016), which is the passengers can be exposed by noise level of 88 dBA no longer than 2 hours per day. The noise inside train are affected by speed of train, which is the higher train speed, the higher noise level inside the cabin. Vibration on the floor were measured with accelerometers. On each measurement point, floor vibration were measured at three directions; Longitudinal, lateral, and vertical. The frequency range applied in this measurement was 0.4-30 Hz and The ride comfort evaluation was evaluated by Sperling's Ride Index. The results show that, the measured noise in the cabin is at the level that is permissible according to Regulation of the Minister of Health No. 70 (2016), which is the passengers can be exposed by noise level of 88 dBA no longer than 2 hours per day. The noise inside train are affected by speed of train, which is the higher train speed, the higher noise level inside the cabin. On the other hand, vibration inside cabin indicate "More pronounced but not unpleasant" zones. This means that the passengers are not much affected by the vibration as they are exposed to low level of vibration*

Keywords*: vibrations, noise, Sperling's Ride Index, comfort*

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I. Introduction

A train is a popular means of transport for several reasons: (1) it runs through the central of the city where people spend little time to reach to their destinations compared to the aircraft where it arrives several kilometers away from the center of the city; (2) it is more economical to travel in medium and long-distance range, (3) it carries several hundred passengers per travel compared to the other means of transports (e.g. buses and domestic aircrafts) and (4) it provides better safety and comfort. Therefore, businessman, students and workers are using trains as a means of their transport back and forth to their jobs in their daily lives. The ride comfort is one of the most important rail vehicle assessment standards. The ride comfort is given by several different adverse effects which passengers are subject on. [1]. Noise and vibration have an important influence on a passenger's perception of vehicle quality and cabin interior noise levels are a key criteria. One of the highest in-cabin noise levels now arises from heating, ventilating and air conditioningsystems, generated by the air-rush noise at various HVAC settings.The dynamic performance of a railroad vehicle as related to safety is evaluated in terms of specific performance indices. The quantitative measure of ride quality is one of such performance indices. Ride quality is interpreted as the capability of the railroad vehicle suspension to maintain the motion within the range of human comfort and or within the range necessary to ensure that there is no damage to the cargo it carries. The ride quality of a vehicle depends on displacement, acceleration, rate of change of acceleration and other factors like noise, dust, humidity and temperature. There are two approaches generally used to evaluate the ride quality of a vehicle: the ride index method and the fatigue time method. The Sperling's ride index (Wz) is the ride index used by Indonesian Railways to evaluate ride quality and ride comfort. Ride comfort implies that the vehicle is being assessed. According to the effect of the mechanical vibrations on the human body, whereas ride quality implies that the vehicle itself is being judged.

Not only vibration, but also noise must be measured and assessed in regard to passenger's comfortness. One of the most significant reasons for the interior noise of the train is the vibration that is created due to the contact of the wheel and the rail, especially when the train passes over the joints in railway tracks. The sources of the vehicle interior noise can be classified into categories such as equipment noise, airborne noise, aerodynamic noise, and the structureborne noise. Equipment such as air-conditioners and ventilation systems are responsible for the equipment noise. Aerodynamic noise originates from the turbulent boundary layer or low separation acting on the vehicle structure. The air-borne noise, generated from various sources, propagates into the interior of the train throughthe vehicle structure or through the gaps in gangways orwindows and its components are usually above 200 Hz [2].This paper deals with the measurement and assessment of the interior noise and vibration of a cabin train during the operational speed. Sound pressure levels and vibration were measured in a cabin while it wasmoving throughout the rail. Noise and vibration measurement data are analyzed to determine the possible perception which might arise from the train passengers. It has been found that the interior noise level exposed to the passengercompartment exceeded the allowed level in a cabin train, whereas, the vibration level measured was still in an acceptable level regarding the passanger’s perception.

II. Methods

Vibration Measurement

Vibration on the floor were measured with accelerometers. On each measurement point, floor vibration were measured at three directions; Longitudinal, lateral, and vertical. The location of the points depicted on **Fig.1**, there are two point located on the center of boogies. The first point was located near the operator room, the other point on the back of cabin. The frequency range applied in this measurement was 0.4-30 Hz. In this frequency range, a human is more sensitive to dynamic response. To get maximum dynamic response, the measurement was carried out the measurement at the operational speed of 60 km/h.

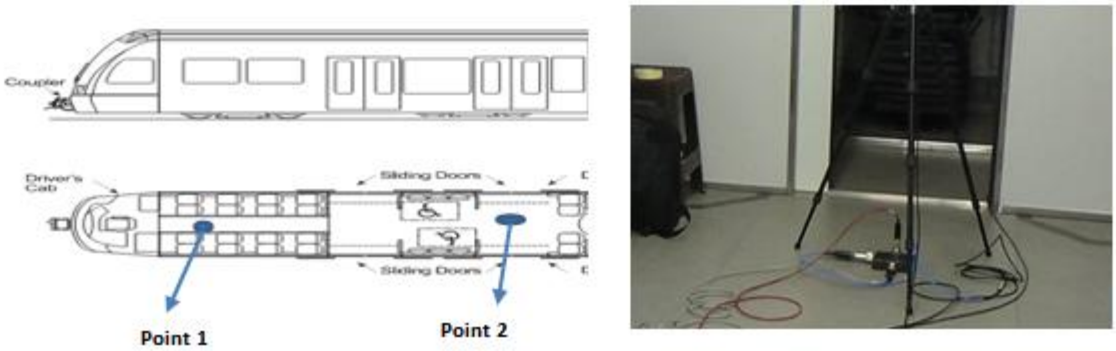


Figure 1: The location of measurement points

On this measurement, B&K Pulse LAN XI and three accelerometers CSI A0760GP were applied as sensors and data acquisition system. Fig. 2 describes set up of the data acquisition system. Vibration response on the floor were captured with accelerometers, afterwards accelerometer signal is converted from analog to digital and processed in the notebook

Figure 2: set up of the data acquisition system

Noise Measurement

The train being measured in this research consist of three coaches. Interior noise of the train was measured in the first coach, a trailer with a driver's cab and passenger coach. The measurement are performed in two conditions, first is static measurement (cabin noise measurement when train in stationary condition with all of the equipment was ON, located in the depo) and the second is dynamic measurement, noise was measured inside the moving train. The aim of static measurement is to measure background noise inside the cabin. Figure 3 is a photograph of the position of a single microphone used in measuring noise inside the coach for static measurement. Sound pressure level was measured at 1/3 octave band in frequency range 31.5 Hz - 16 kHz.

Figure 3: Microphone position for static measurement (outside view)

While for dynamic measurement, the measurement points of the interior noise are presented in Figure 4. There are four microphones that was positioned near the driver's cab (P1), in the centre of the coach (P2 and P4) and at the end of the coach (P3). Microphone P1, P2 and P4 are positioned at height 1.6 m above the cabin floor (represent the height of standing human's ears), whereas microphone in P3 was positioned at 1.2 m above the cabin floor (represent the height of sitting human's ears). Test conditions for dynamic measurement are summarized in **Table 1**,

Table no 1 : Test conditions for dynamic measurement

Measurement condition	**Cabin noise measurement at train speed, v = 60 km/h)**	**Variation in train speed (40 km/h, 50 km/h dan 60 km/h)**
Microphone position	P1, P2, P3 and P4	P1
Analysis method	Overall SPL, frequency analysis	
Result	• sound pressure level (SPL) vs train speed • Frequency characteristics	

From the table above, it can be seen that the test conditions for dynamic measurement can be grouped into two sets : different speeds and different position of the observer at the certain speed of train.

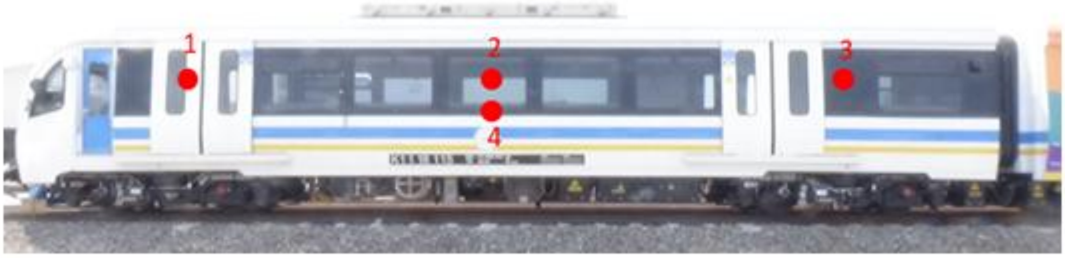
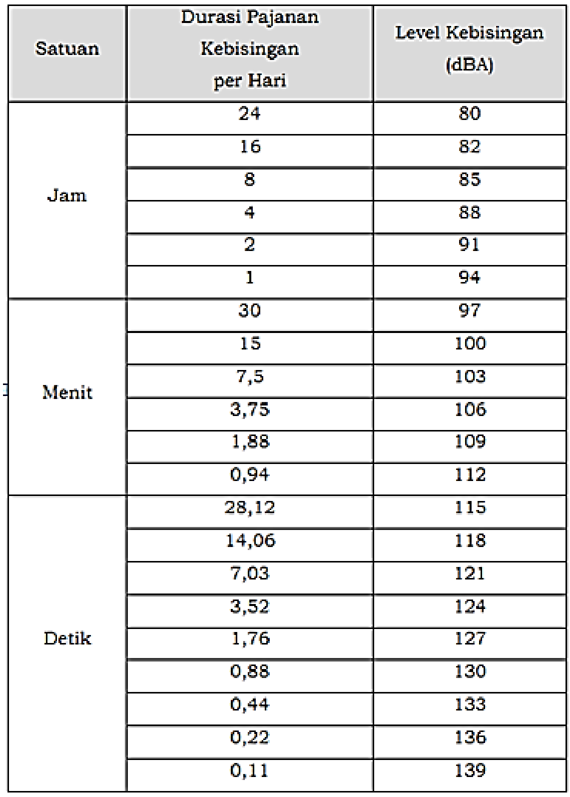


Figure 5 : Microphone position for dynamic measurement (outside view)

Noise Evaluation Toward Passenger Comforts

The influence of noise on passenger comforts depend on the criteria being used. In general, loudness can interfere with hearing. In some other cases sounds that are not too loud can also interfere with hearing. In this measurement, the noise level in the cabin is evaluated by referring to Regulation of the Minister of Health No. 70 of 2016 for measurement in dynamic conditions (Table no 2) [3].

Table no 2: Threshold hearing level (Regulation of the Minister of Health No. 70 / 2016)



Satuan	Durasi Pajanan Kebisingan per Hari	Level Kebisingan (dBA)
Jam	24	80
	16	82
	8	85
	4	88
	2	91
	1	94
Menit	30	97
	15	100
	7,5	103
	3,75	106
	1,88	109
	0,94	112
Detik	28,12	115
	14,06	118
	7,03	121
	3,52	124
	1,76	127
	0,88	130
	0,44	133
	0,22	136
	0,11	139

Sperling Ride Index (Wz)

Sperling proposed a ride index and developed the so-called Wz method (Werzungzahl). Wz is a frequency weighted r.m.s value of accelerations evaluated over defined time intervals or over a defined track section. For an arbitrary acceleration signal which is not necessarily a harmonic signal the frequency weighted root mean square value of accelerations should be used. To determine Sperling's Ride Index, this equation is applied as below [4];

$$Wz = (a^3 b^3)^{1/10} \qquad (1)$$

where a is the amplitude of acceleration in cm/s^2 and B the acceleration weighting factor. The frequency weighting factors for ride comfort in different directions. The weighting factor B for ride comfort in the horizontal direction is given by

$$B_w = 0.737\left[\frac{1.911f^2 + (0.25f^2)^2}{(1-0.277f^2)^2 + (1.563f - 0.0368f^3)^2}\right] \qquad (2)$$

The weighting factor B for ride comfort in the vertical direction is given by[Gangadharan]

$$B_s = 0.588\left[\frac{1.911f^2 + (0.25f^2)^2}{(1-0.277f^2)^2 + (1.563f - 0.0368f^3)^2}\right] \qquad (3)$$

The vibration is not at a single frequency, but encompasses a whole spectrum of frequencies in which the natural frequencies of the vehicle are very much pronounced. In such cases, the ride index calculation has to be done for the entire spectrum. The Wz ride factor is determined for each individual frequency from Equation (1) and the total Wz factor is calculated as

$$Wztotal = (Wz1^{10} + Wz2^{10} + Wz3^{10} + \wedge + Wzn^{10})^{1/10} \qquad (4)$$

Wz value of 2.5 is often compared to ISO weighted r.m.s. acceleration value of 0.25 m/s^2. This value is often considered as acceptable for ride comfort on trains with respect to motions and vibrations. Table 1 gives the relationship between the ride index and vibration sensitivity.[5]

Table no 3: Ride evaluation scale as per Sperling ride index

Ride Index Wz	Vibration sensitivity
1	Just noticeable
2	Clearly noticeable
2.5	More pronounced but not unpleasant
3	Strong, irregular, but still tolerable
3.25	Very irregular
3.5	Extremely irregular, unpleasant, annoying, prolonged exposure intolerable
4	Extremely unpleasant ; prolonged exposure harmful

Sperling's ride Index (Wz) is more convenient than ISO 2631, because it eventually produces in a number. Thus is easier to compare two or more different situations.

III. Result and Discussion

Cabin Noise Evaluation

The measurement result for cabin noise are evaluated by comparing the measurement values and allowable noise threshold value contained in the regulation of the Indonesia Ministry of Health No. 79 (2016). Based on measurement results shown in Table 5, the highest overall sound pressure level (OA SPL) inside the moving train is 92.5716 dBA i.e. at position P3. Referring to regulation, the noise at that level could be received by passengers with exposing duration no more than one hour per day. Comparison of the interior noise in the cabin between static and dynamic condition are presented in Fig. 6.

Table no 4: Evaluation of Measurement Data for Dynamic Condition

Microphone position	SPL Overall (dBA)	Maximum Exposure Duration
P1	90.6992	No longer than 2 hour/day
P2	88.9535	No longer than 2 hour/day
P3	92.5716	No longer than 1 hour/day
P4	87.3166	No longer than 2 hour/day

Based on **Fig. 6**, when train was moving at certain speed (60 km/h), it can be seen that between frequencies of 315 Hz to 4000 Hz, there are sound contribution from source other than HVAC system, such as friction and vibration due to interaction between train wheel and the rail, noise that come from the vibration of the bogie, electric collector friction and wind noise which increases the noise level (overall) in the cabin. Besides, the air-borne noise, generated from various sources outside the train propagate into the interior through the wall panels and floors, therefore good transmission loss characteristic of the material is necessary to be applied in terms of driving out sound from the outside. At this speed, the aerodynamics noise are not dominant. Another factor that also affect the noise level in the cabin is the type of track crossed by the train. There are two types of tracks commonly used, namely ballasts and slab tracks. The ballast track has a lower vibration and a higher vibration decay rate than the slab track type, this is due to the different in stiffness of the rail pad. In addition, at high frequencies, ballasts can be used as sound-absorbing material [6][7].

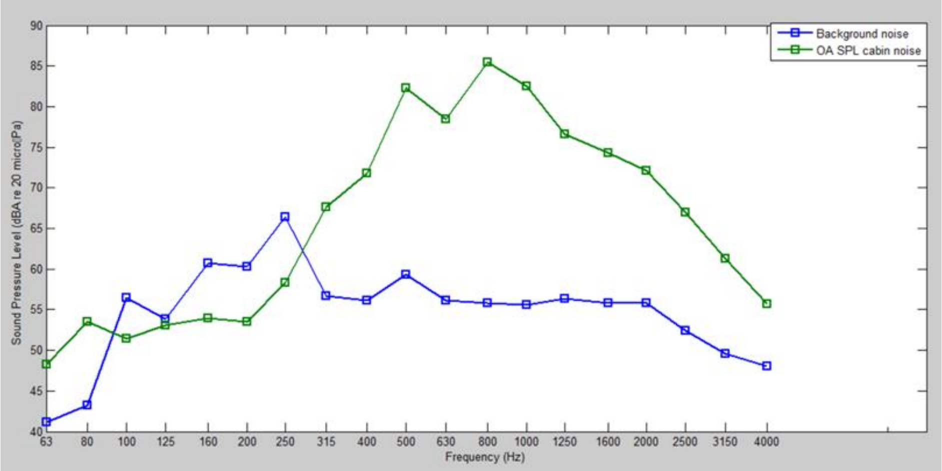


Figure 6 : Comparison of the interior noise in the cabin between static and dynamic condition

Effect of Train Speed on Cabin Noise Level

To identify the noise level emitted when train speed increased, when the value of $L_p(v_0)$ at reference speed v_0 is known, the linear regression law can be expressed with the following approaches [8][9][10]:

$$L_p(v) = a\ \log(v/v_0) + L_p(v_0) \qquad (5)$$

where$L_p(v)$ is the sound pressure level when train speed is v, a is a coefficient, $L_p(v_0)$ is sound pressure level at reference speed v_0. The value of a is in the range of 25 to 35 and usually has value 30. For speed below 100 km/h used the value $a = 20$, while at speed 100 - 300 km/h , $a = 30$. In this study, $a = 20$ was used because the speed of the train was below 100 km/h. From the previous data obtained from measurement and by using equations (5) it can be predicted the interior noise level at different speeds of the train.

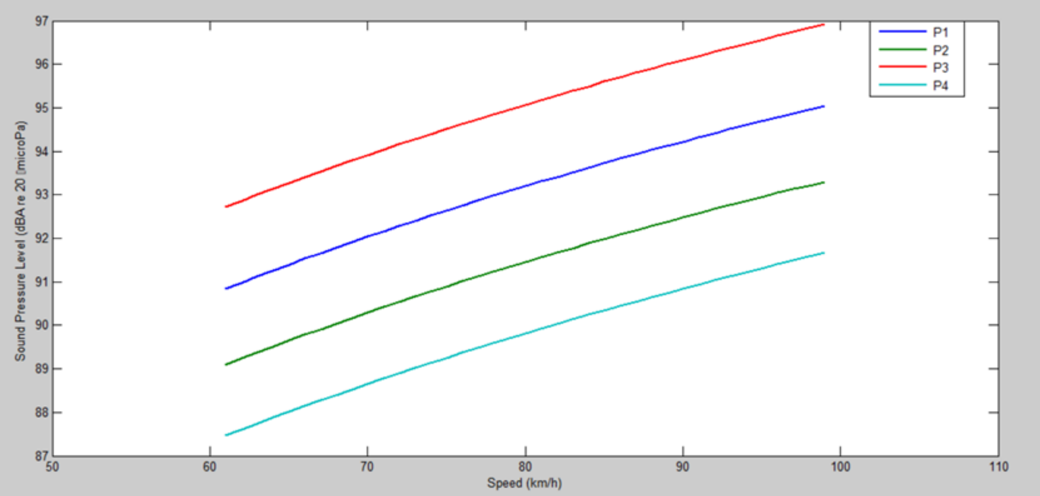
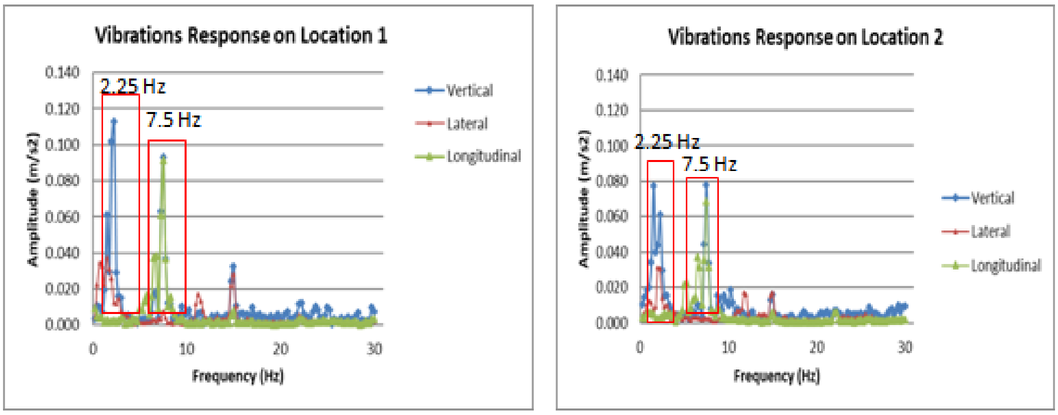


Figure 7: Cabin noise levels at different speeds

From Fig. 7 it can be seen that noise inside the train all increase with the increment of the speed for all the measurement position (P1,P2, P3 and P4). The increasing of train speed leads to higher rolling noise, that is noise generated by the interaction between the rotation train wheel and the rail. This type of noise is the most important source of noise both inside the train and surrounding environment.

Cabin vibrations evaluation

The ride comfort evaluation was evaluated by Sperling's Ride Index. Frequency range of measurement is between 0.4-30 Hz in which human is likely to be sensitive on vibration motions. The frequency spectrums of vibrations measurement on each location 1 is depicted on Fig.xx. On location 1, vertical and lateral vibrations peaked on around 2.25 Hz, while the peak of longitudinal occurred on around 7.5 Hz. Similiarly, on location 2, vertical and lateral vibrations reached the most dominant peak on around 2.5 Hz, whereas, longitudinal vibration peaked on around 7.5 Hz.



(a) (b)

Figure 8: Vibrations response on each location

The Wz Ride Index (RI) is determined for each direction by using equation (1) with weighting of frequency on each direction using equation (2) and (3). In this study Wz is calculated for vertical and lateral directions on each measuring point separately. The results of vibration measurements are shown in Table 3. In all the measured sections Sperling ride Index values are (maximum 2.22) well within the comfort level by Wz. These values respectively indicate “More pronounced but not unpleasant” zones. This means that the passengers are not much affected by the vibration as they are exposed to low level of vibration

Table no 5: Sperling’s Ride Index

Location	**Direction**	**Sperling's Ride Comfort (Wz)**	**Category**
1	Vertical	2.22	Not upleasant
	Lateral	1.68	Clearly Noticeable
2	Vertical	2.01	Not upleasant
	Lateral	1.58	Clearly Noticeable

IV. Conclusion

The measured noise in the cabin is at the level that is permissible according to Regulation of the Minister of Health No. 70 (2016), which is the passengers can be exposed by noise level of 88 dBA no longer than 2 hours per day. Under stationary condition, HVAC operations increase noise (SPL overall) in the cabin from 44.46 dB to 70.76 dBA. On the dynamic condition of the train, the overall noise level increases from 70.76 dB to the level of 92,517 dBA (maximum at microphone position P3). This additional noise source come from friction due to interaction between wheel and rails, electric collector friction with third rail, poor sound insulation at the cabin wall, and the type of rail bearing used. The higher the train speed, the higher noise level inside the cabin. Based on vibrations measurements, vibration inside cabin indicate “More pronounced but not unpleasant” zones. This means that the passengers are not much affected by the vibration as they are exposed to low level of vibration.

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