Figure 1: Overview of the CPX tyre/road noise measurement system

2.2 Test method

Two road sections paved with porous asphalt (**P**olymer **M**odified **F**riction **C**ourse) and dense asphalt (**W**earing **C**ourse) surface respectively are selected. CPX measurements at reference speeds of 50 and 70 km/h are conducted with four **Yokohama C.drive AC01 (185/65 R15)** tyres (a locally popular passenger car tyre). The test tyres were worn to different extent by travelling on roads during surveys in previous years. Figures 2a and 2b show their tread hardness and depth. By comparing **tyres 1 AND 3** or **tyres 2 AND 4**, the tread hardness influence on noise can be inspected while the tread depth effect can be evaluated by comparing ***tyres 2 AND 3*** or ***tyres 3 AND 4***.

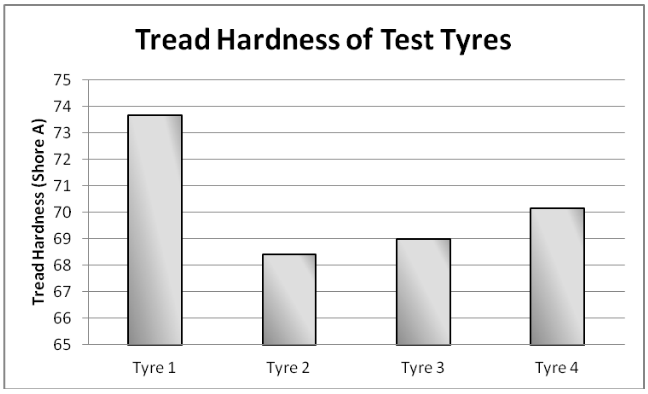

Figure 2a: Tread hardness of the four test tyres

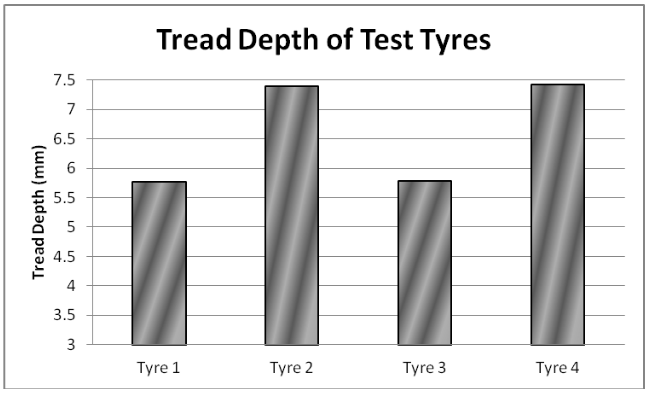

Figure 2b: Tread depth of the four test tyres

3 RESULTS AND DISCUSSION

3.1 Tyre/road noise level

The measured tyre/road noise levels with the four test tyres are compared. Figures 3a and 3b shows the noise levels measured at the two reference speeds on dense and porous asphalt surfaces respectively. From Figures 3a, the differences between measured noise levels on porous road surface by the four tyres at both reference speeds are within 1 dB. Similar observation is noted in the case of dense asphalt surface as shown in Figure 3b. To compare whether there is any statistical significant difference between the noise levels by the test tyres, T-test is applied to the compare the measured noise levels.

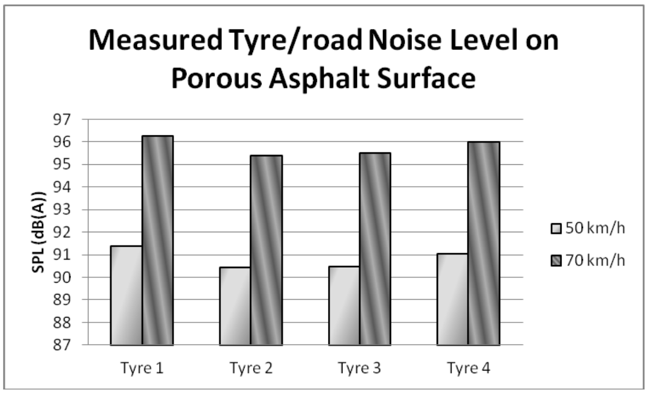

Figure 3a: Measured tyre/road noise levels on porous asphalt surface of the four test tyres

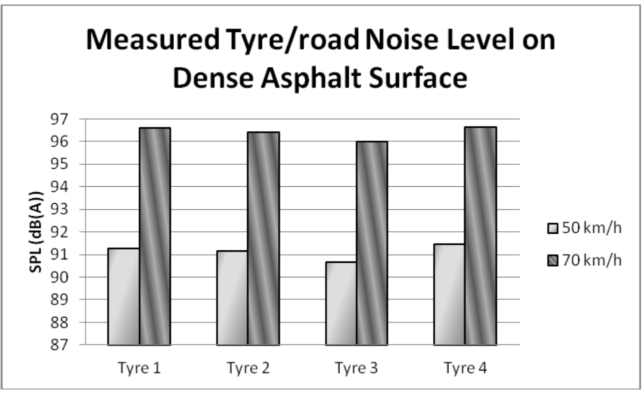

Figure 3b: Measured tyre/road noise levels on dense asphalt surface of the four test tyres

3.2 Statistical comparison on the tyre/road noise level

T-test at 5% p-value is conducted by comparing the noise level data set of one test tyre to another on the same road surface at the same reference speed. Tables 1a – 1b show the p-value of individual T-test for comparison on any two tyres. Those p-values below 0.05 are underlined. Table 2 has summarized all those noise level numerical differences with tyres combination making up a significant statistical difference.

PA 50 km/h

p-value	Tyre 1	Tyre 2	Tyre 3	Tyre 4
Tyre 1		0.00	0.00	0.01
Tyre 2			0.83	0.00
Tyre 3				0.00
Tyre 4				

Table 1a: T-test p-value between noise levels by individual tyres on porous asphalt surface at 50 km/h

PA 70 km/h

p-value	Tyre 1	Tyre 2	Tyre 3	Tyre 4
Tyre 1		0.00	0.00	0.01
Tyre 2			0.48	0.00
Tyre 3				0.00
Tyre 4				

Table 1b: T-test p-value between noise levels by individual tyres on porous asphalt surface at 70 km/h

DA 50 km/h

p-value	Tyre 1	Tyre 2	Tyre 3	Tyre 4
Tyre 1		0.51	0.00	0.02
Tyre 2			0.00	0.00
Tyre 3				0.00
Tyre 4				

Table 1c: T-test p-value between noise levels by individual tyres on dense asphalt surface at 50 km/h

DA 70 km/h

p-value	Tyre 1	Tyre 2	Tyre 3	Tyre 4
Tyre 1		0.39	0.00	0.72
Tyre 2			0.00	0.21
Tyre 3				0.00
Tyre 4				

Table 1d: T-test p-value between noise levels by individual tyres on dense asphalt surface at 70 km/h

Surface type	Speed (km/h)	SPL difference (dB)					
		T1 – T2	**T1 – T3 (> 4.67 Sh A)**	T1 – T4	***T2 – T3 (> 1.61 mm)***	**T2 – T4 (< 1.75 Sh A)**	***T3 – T4 (< 1.64 mm)***
Porous asphalt	50	+ 1.0	**+ 0.9**	+ 0.4	***N/A***	**– 0.6**	***– 0.5***
	70	+ 0.9	**+ 0.8**	+ 0.3	***N/A***	**– 0.6**	***– 0.5***
Dense asphalt	50	N/A	**+ 0.6**	– 0.2	***+ 0.5***	**– 0.3**	***– 0.8***
	70	N/A	**+ 0.6**	N/A	***+ 0.4***	**N/A**	***– 0.6***

Table 2: Numerical noise level difference by tyres combination with T-test p-value under 0.05

Referring to the tyre properties shown in Figures 2a and 2b, we can inspect tread hardness influence by comparing **tyres 1 AND 3** or **tyres 2 AND 4**, and we can evaluate the tread depth effect by comparing ***tyres 2 AND 3*** or ***tyres 3 AND 4***. The analyses on the two effects are discussed below.

Tread hardness effect

From Table 2, the columns of **"T1 – T3"** and **"T2 – T4"** indicate that harder tread rubber results in higher tyre/road noise in most speed/surface combinations. This finding complies with researches[1] on tyre/road noise elsewhere. The extents of tread hardness influence are +0.18 to +0.34 dB/Sh A and +0.13 to +0.17 dB/Sh A for porous and dense asphalt road surfaces respectively.

Tread depth effect

From columns of ***"T2 – T3"*** and ***"T3 – T4"*** in Table 2, it is observed that tyre with lower tread depth produces less tyre/road noise on dense asphalt surface at a rate of –0.28 to –0.43 dB/mm ***drop of tread depth***. Nevertheless, such observation does not apply to the case of porous asphalt surface as there exist no consistent relationship between the noise level and tread depth differences.

4 CONCLUSIONS

Results of CPX measurements with four **Yokohama C.drive AC01 (185/65 R15)** tyres with different tyre rubber hardness and tread depth indicate that tyres with higher tyre rubber hardness produces higher noise on both porous and dense asphalt surfaces. The extents of influence are +0.18 to +0.34 dB/Sh A and +0.13 to +0.17 dB/Sh A for porous and dense asphalt road surfaces respectively. For tread depth effect, results show that lower tread depth produces less tyre/road noise on dense asphalt surface at rate of –0.28 to –0.43 dB/mm ***drop of tread depth***.

ACKNOWLEDGEMENTS

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References

[1] Sanberg U. and Ejsmont J. A., (2002) *Tyre/Road Noise Reference Book*. Informex Ejsmont, Modena.

[2] Hung, W.T., Lam, Y.K., NG, C.F., Leung, R.C.K., Ho, K.Y. and Fung, E. (2011), "Certifying a twin-wheeler CPX vehicle for tyre/road noise measurement", CD ROM, Proceedings of Inter-Noise 2011, 4-7 September 2011, Osaka, Japan.

[3] International Organization of Standardization, (2009) ISO/CD 11819 – 2 *Measurement of the Influence of Road Surfaces on Traffic Noise: The Close-proximity (CPX) Method*. Geneva Switzerland.

麥克風震盪對輪胎噪音近距測量法（CPX）的影響
Impact of Microphone Vibration on Tyre/road Noise Measurement with Close-Proximity (CPX) Method

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Abstract: Laboratory and on-road experiments are devised to test for influence of microphone vibration on the tyre/road noise level measured with Close-Proximity (CPX) method. Results show that vibration-induced error exists and traceable relationship of it with the vibration level is found. An attempt to correct such error is demonstrated with a case study, showing that microphone vibration can introduce significant error to the tyre/road noise measurement results.

Key words: tyre/road noise; CPX; vibration, error

摘要：本文以實驗室及路上測試找尋麥克風震盪對輪胎噪音近距測量法（CPX）的影響。結果顯示該振動導致噪音量度結果出現顯著誤差，並發現兩者有可追溯的關係。本研究試圖建立方法糾正這種錯誤，並以案例闡明。

關键詞：輪胎噪音；CPX；震動；誤差

1 INTRODUCTION

Close-Proximity (CPX) method is a standard[1] tyre/road noise measurement in which a trailer equipped with test tyre(s) and microphones is towed to travel on test road sections at a certain reference speed. The tyre/road noise emitted is directly measured by the microphones mounted close to and pointing at the tyre/road contact patch. This measurement method can be used for assessing tyre/road noise performance of real public roads under normal traffic. Figure 1 shows the overview of the twin-wheeled CPX measurement system used in this study. It was developed and certified[2] in 2009 at The Hong Kong Polytechnic University. The trailer has an acoustic enclosure for shielding external noise with minimized internal reflection. The two test tyres and two microphones assigned for each are mounted inside.

Figure 1: Overview of CPX tyre/road noise measurement

In most experimental practices, microphone is placed stationary at the measuring point and remains intact throughout the measurement. This is because movement and vibration of it may induce error to the measured noise signal owning to its sensing mechanism[3] by detecting air pressure fluctuation through vibration of microphone diaphragm relative to the back plate electrode. It is a matter of fact that microphone produces electric signal when it is vibrated. Some researchers[4] even make use of this properties to measure vibration using microphone. Since public roads can be of great variety in roughness and bumpiness, vibration maybe imposed from the road and transmitted to the mounted microphones as the CPX trailer travels on it. The measured noise signal may then be contaminated with an additional vibration-induced signal component. This erroneous component is termed as “vibration-induced error” in this paper. Equation 1 expresses the hypothetic relationship between the measured noise level at vibration level, the actual tyre/road noise level and the vibration-induced error.

$$SPL_{L_{\ddot{x}}} = SPL_{actual} + E(L_{\ddot{x}}) \qquad \ldots\ldots\ldots (1)$$

2 METHODOLOGY

Laboratory and on-road experiments are devised for testing the microphone vibration influence on its measured noise signal based on comparing the respective measured noise levels when the microphone is stationary and vibrated. Both tests utilize the same speaker for emitting white noise as a controlled sound source. Vibration is excited to the microphone by shaker and road bumpiness for the laboratory and on-road tests respectively. Analysis is made to search for any traceable relationship between the vibration level and the vibration-induced error in the measured noise level. Equation 2 express the definition of the error term as the difference between the noise levels measured when the microphone is at vibration level $L_{\ddot{x}}$ and when it is stationary.

$$E(L_{\ddot{x}}) = SPL_{L_{\ddot{x}}} - SPL_{static} \qquad \ldots\ldots\ldots (2)$$

For both tests, the microphone vibration is measured with the microphone/accelerometer setup kit designed as shown in Figure 2. The ***x*** and ***y*** axes denote the measuring directions of the accelerometer and the microphone respectively. This kit is screwed and mounted to the frame of the CPX trailer rigidly. It is utilized in both the laboratory and the on-road tests.

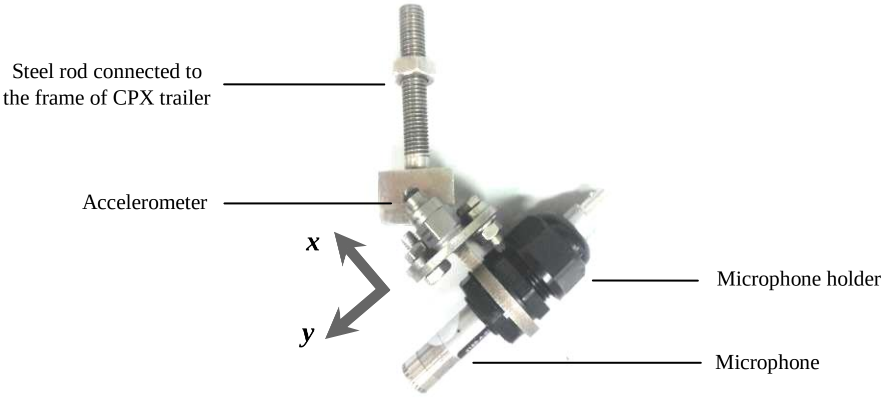


Figure 2: Microphone/accelerometer kit for measuring the vibration of microphone

2.1 Laboratory Experiment

As it is practically infeasible to put the entire CPX trailer into the anechoic chamber, a replica of its microphone mounting frame is made for the laboratory test. It is also equipped with the microphone/accelerometer kit shown above and is vibrated by a shaker. Figure 3 shows the setup of the test. The shaker is hanged over the air with the orientation offering vibration to the frame replica at horizontal direction. The mounted microphone is oriented pointing towards the speaker emitting white noise. The ***x*** and ***y*** axes are defined the same way as in Figure 2. The analysis is done by comparing the measured noise levels in cases when the shaker is ON and OFF respectively.

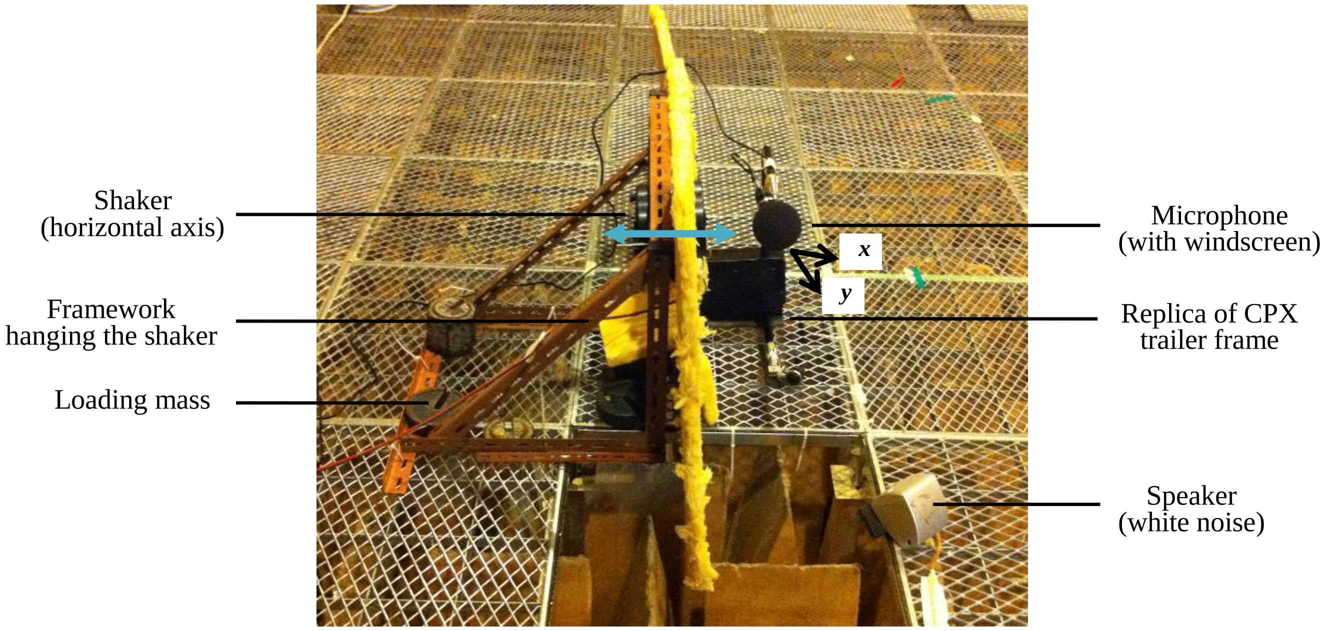


Figure 3: Setup of the laboratory test for the microphone vibration impact on the measured noise

2.2 On-road Experiment

The test concept of the on-road experiment is the same as that of the laboratory measurement in which the method of analysis is also based on comparing the measured noise levels in vibrated and stationary conditions of the microphone. The main differences of the setup are that the whole CPX trailer is used this time and the vibration excitation is offered by the road bumpiness transmitted to the trailer via the vehicle.

The trailer is rigidly fixed onto the deck of the light goods vehicle as shown in Figure 4 so that the sound source can be controlled with a speaker placed inside emitting white noise, and the uncontrollable tyre/road noise can be eliminated as the tyres are not rolling. The measured noise when the vehicle is stationary is compared to that when it is travelling with vibration transmitted to the microphone.

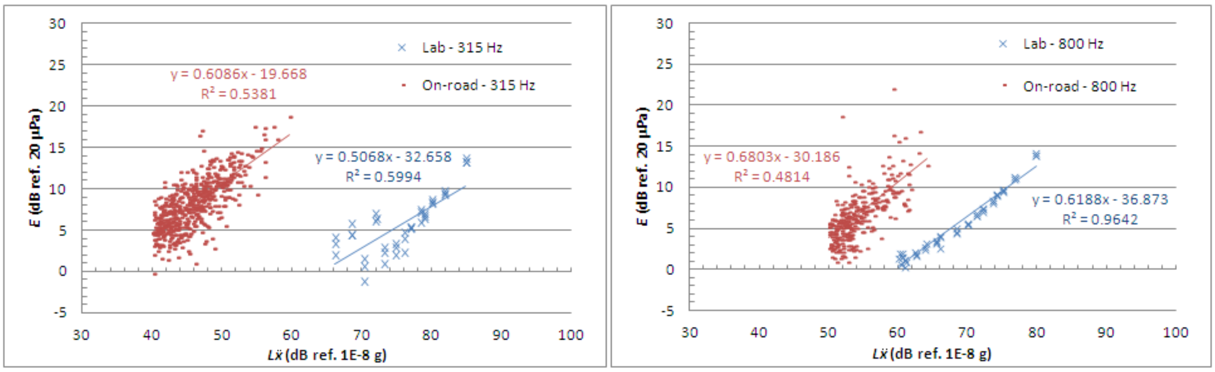
Figure 4: Setup of the on-road test with the CPX trailer fixed onto the deck of the light goods vehicle

3 RESULTS AND DISCUSSION

For both the laboratory and on-road experiments, the 1/3-octave spectra of the measured noise and the microphone vibration are computed. The vibration-induced error of a frequency band in the measured noise is computed with the band levels yielded from the vibrated and stationary cases using Equation 2. The error is plotted against the vibration level of the same band to search for any observable relationship.

Traceable linear relationship between the vibration-induced error and the vibration level is observed in both laboratory and on-road experiments for five bands (315, 400, 500, 800 and 1000 Hz). Figures 5a and 5b show two typical plots. Under the same vibration level, the error in the on-road case is higher than that in laboratory case. This may be caused by additional unknown noise event when the trailer is vibrated in field environment. With the trend line equations, the error can be estimated from the microphone vibration level. Notice that only positive value of error is accepted since it is assumed that vibration induces positive deviation to the measured noise level. The trend line equations are listed in Table 1.

Vibration-induced Error against Vibration Level



Figures 5a – 5b: Vibration-induced error (dB ref. 20 μPa) against vibration level (dB ref. 1×10^{-8} g)

Table 1: Yielded trend lines between vibration-induced error and vibration level from laboratory and on-road experiments

1/3-octave band (Hz)	Laboratory Experiment		On-road Experiment	
	Trend Line Equation	Goodness of fit (R^2)	Trend Line Equation	Goodness of fit (R^2)
315	$E = 0.5068L_{\ddot{x}} - 32.658$	0.60	$E = 0.6086L_{\ddot{x}} - 19.668$	0.54
400	$E = 0.5385L_{\ddot{x}} - 35.548$	0.88	$E = 0.6611L_{\ddot{x}} - 34.094$	0.35
500	$E = 0.4944L_{\ddot{x}} - 30.432$	0.94	$E = 0.8889L_{\ddot{x}} - 47.323$	0.55
800	$E = 0.6188L_{\ddot{x}} - 36.873$	0.96	$E = 0.6803L_{\ddot{x}} - 30.186$	0.48
1000	$E = 0.6353L_{\ddot{x}} - 38.882$	0.95	$E = 0.8253L_{\ddot{x}} - 45.372$	0.44

4 Evaluation Study

The microphone vibration data in an ordinary CPX measurement on a concrete road surface at reference speed 70 km/h is collected. A case study attempting to estimate the vibration-induced error and make a correction to the measured tyre/road noise is demonstrated. Figure 6 shows the microphone vibration level measured. Using the vibration band levels, the vibration-induced error in the noise spectra is estimated using the equations in Table 1, and correction is applied through subtracting this erroneous component from the measured band levels. Figure 7 shows the noise spectra of the original and the corrected ones using the equations yielded from laboratory and on-road measurements respectively.

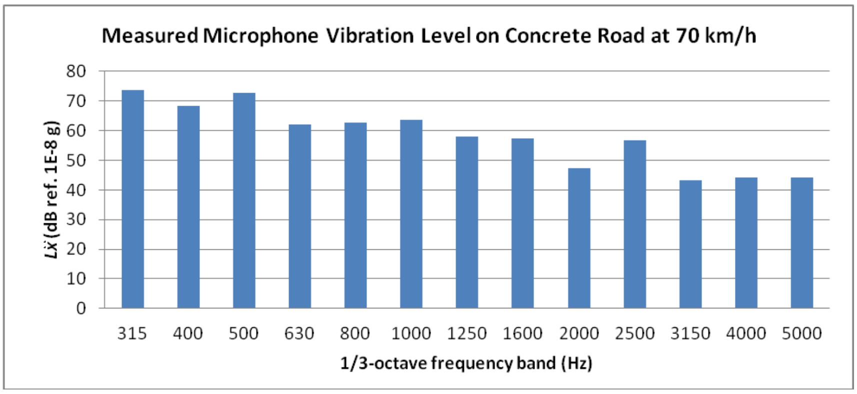


Figure 6: Measured Microphone Vibration Level in a CPX measurement

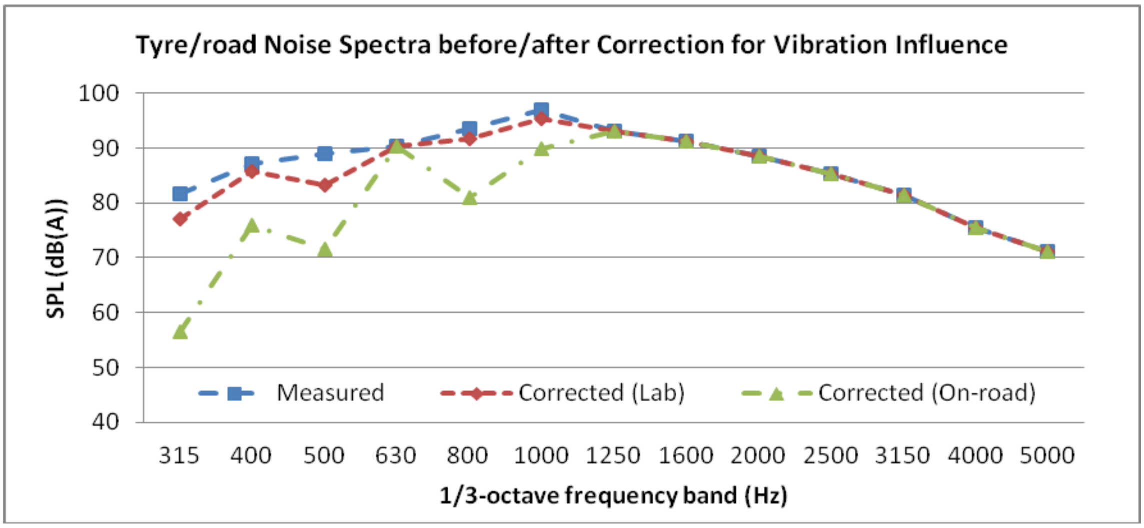


Figure 7: Tyre/road noise spectra before/after correction for vibration influence

From Figure7, the noise spectra after correction using the trend line equations yielded from laboratory and on-road experiments have similar pattern in which there are dips at 500 Hz and 800 Hz. The overall tyre/road noise level of from measurement and those corrected with laboratory and on-road results are 101.6, 100.5 and 98.3 dB(A) respectively. A reduction of about 1 or even 3 dB is registered after the correction. The vibration induced error on the measured tyre/road noise level is significant.

5 CONCLUSIONS

Laboratory and on-road experiments are devised to test for influence of microphone vibration on the measured tyre/road noise level with CPX method. Traceable relationship between the error and vibration level is found for five frequency bands and correction method is developed. A case study demonstrated shows that the vibration-induced error can alter the noise spectral shape and the overall tyre/road noise level can be deviated up to +3 dB which is significant to the measurement results.

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References

[1] International Organization of Standardization, (2009) ISO/CD 11819 – 2 *Measurement of the Influence of Road Surfaces on Traffic Noise: The Close-proximity (CPX) Method*. Geneva Switzerland.

[2] Hung, W.T., Lam, Y. K., NG, C. F., Leung, R C. K., Ho, K. Y., and Fung, E. (2011), “Certifying a twin-wheeler CPX vehicle for tyre/road noise measurement”, CD ROM, *Proceedings of Inter-Noise 2011*, 4-7 September 2011, Osaka, Japan.

[3] Sander-Rőttcher, H., and Tams, K., “Microphone testing,” Chap. 6 in *Microphone Engineering Handbook*, edited by M. Gayford (Focal Press, 1994)

[4] Watakabe, M., Mita, K., Akataki, K., and Itoh, Y., “Mechanical behavior of condenser microphone in mechanomyography,” *Medical & Biological Engineering & Computing*, Vol. 39, No. 2, 195-201 (2001)

电梯噪声治理新技术—电梯专用静音器

A new technology of elevator noise reduction — elevator scilencer

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Abstract: This paper mainly analysis the machanism and characteristics of elevator noise and introduces a new technology of elevator noise reduction—elevator scilencer

Key words: elevator noise; elevator scilencer

摘要：本文分析了电梯噪声产生的机理和特性，介绍了电梯降噪新技术—电梯静音器并阐明了其技术特性和使用效果。

关键词：噪声治理；电梯专用静音器

1. 概述

我国房地产行业快速发展和多层建筑在中国大地上如雨后春笋般的拔地而起，电梯行业也在中国得到了快速发展。据有关资料介绍，国内的现有电梯使用量已接近 400 万台，每年新增电梯量达到 30 多万台。在这种快速发展过程中，电梯的运行噪声扰民问题日益突出，已成为一个比较普遍新的环境问题。笔者针对这一问题，就多年的研究和实践，研制出一套行之有效的治理技术。经过大量的工程应用，证明本项技术达到了能完全解决电梯振动噪声扰民这一难题水平。

2. 电梯噪声的形成

2.1 电梯设备噪声

电梯的主要构成部分主要有：曳引机、提升钢缆、限速器、轨道、配电柜、轿厢、配重、缓冲器和自动控制系统等组成。其中噪声产生的部件主要有以下三种部位：

2.1.1 曳引机

高速运转的曳引起是产生噪声振动的主要源。曳引起、轿厢、配重、钢缆相连组成一个振动源系统。

2.1.2 配电柜

配电柜的噪声主要由接触器产生，当电梯开启和停止时，接触器的接触开关在脉冲电流的作用下，产生“ 嗒嗒 ”的声音，达到 85dB(A)以上，一般来讲，交流接触器比直流接触器产生的噪声更大。

2.1.3 限速器

限速器的噪声主要是其在运转的过程中产生的振动由固体结构传播产生，其频率特性主要是低频特性。

2.2 电梯噪声的特点

2.2.1 振动力非周期性

如前所述，电梯的振动系统由曳引机、轿厢和配重系统组成，其曳引机在振动时的负载是经常变化，是非周期性的。如上行时，曳引机负载重量较大，下行时负载重量较小，轿厢内乘坐人员的多少也影响着曳引起负载。总之，电梯在运行过程中产生的振动力是变化的，不具备如水泵、制冷机等住房设备的周期性的振动力。

2.2.2 脉冲性随机性

电梯在停止状态到运行时，其速度将产生突变，此时产生的噪声最高的，具有典型脉冲噪声的特性。人们使用电梯的随机性，决定电梯产生的噪声随机性，这种随机噪声对人们的影响要比恒定噪声影响大。

2.2.3 低频性

电梯振动系统产生噪声主要经过固体传声途径进行传播。由于建筑物的楼板、墙体、梁、柱主要由钢筋混凝土等非匀质材料构成，所以当声音在此种固体物质中传播时，由于散射和耗散作用，其高频声的衰减很快，传到受影响点时，只剩下低频声成份。

2.2.4 受影响区域局限性

电梯噪声的影响主要是居住在顶层，电梯机房楼下的人们，一般情况下，电梯井和居民的客厅和厨房共墙时影响更大。

3. 电梯噪声的新技术

针对以上电梯噪声特点，笔者根据多年研究实践，研制一种高效的电梯减振和降噪技术，效果奇佳。经过近两千多台电梯安装使用，其本能达到电梯噪声零排放水平，由于该技术目前还在专利保护期，主要技术要点不便介绍，本文着重介绍其技术性能和使用效果。其外型如图（1）（2）。

图（1）

图（2）