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IMPROVING VEHICLE SOUND MODEL TO SIMULATE ROAD TRAFFIC NOISE

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ABSTRACT

Road traffic noise is still an issue globally. Improved prediction model is needed to consider measures for reducing road traffic noise. Current simulation models for road traffic noise such as CNOSSOS-EU [1][2] and ASJ-RTN (Acoustical Society of Japan-Road traffic noise prediction model) [3] use fixed vehicle sound model. Vehicle sound level will be changed according to tightened sound limit in the regulation every four years.
Updated vehicle sound model depending on noise regulation should be used in order to improve accuracy of calculation results for road traffic noise.
Usually making vehicle sound models needs a lot of measurements like ISO11819-1 (Measurement of the influence of road surfaces on traffic noise – Part1 Statistical Pass-by method). And an impact study of emitted sound from vehicle needs sound model with consideration of powertrain sound and tire/road sound separately and of categories having different sound limit in the regulation.
The proposed idea as first step is a method for making sound model for a vehicle with less measurements. And the method can be applied to every vehicle category.

Keywords: *road traffic noise, vehicle noise, sound power level, noise regulation*

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1. INTRODUCTION

There are several prediction models for road traffic noise. Those models as well as ASJ-RTN are used fixed vehicle sound source model. The calculation formulas for the sound sources for ASJ-RTN were made by measured data which had been performed on roadsides in mainly 1990's.
Afterwards, the formulas were reviewed with additional data every five years, but they are almost unchanged. [3][4][5]
Fig. 1 shows history of sound limit for vehicle regulation in Japan. Japan had the original regulation but similar sound limit to European and has introduced UN regulation No.51 (R51-03: Uniform provisions concerning the approval of motor vehicles having at least four wheels with regard to their sound emissions) since 2016. R51-03 has three-step lower sound limits. Tire noise regulation, UN regulation No.117 (R117-02: Uniform provisions concerning the approval of tyres with regard to rolling sound emissions and/or to adhesion on wet surfaces and/or to rolling resistance), was introduced in 2018 in Japan. In actual traffic flow, several different type of vehicles are combined such as vehicle with old certification (old sound limit) or categories. Average life span in Japan is 13.2 years for passenger car, 17.2 years for truck, and 20.7 years for bus. [5] Furthermore, consideration for rapidly increased electric vehicle (EV) and hybrid vehicle (HEV) is needed as well. Sale volume of EV and HEV in Japan is already 56% for passenger car in 2022. [6]
Although updating the sound source model is needed, it is not easy to make revised them according to usual way.
A concept of developing sound source model in any stage of regulation is proposed. And procedure of determining the sound power level formula for an individual vehicle is shown as first step with consideration of simple measurement as much as possible.

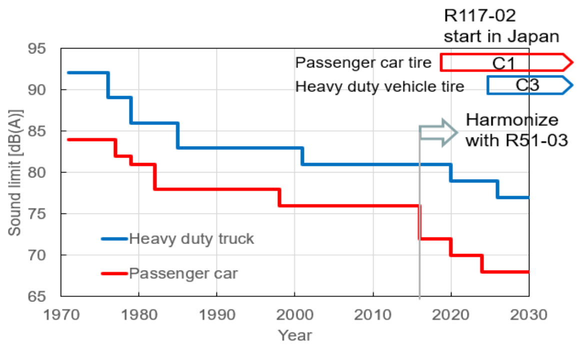

Figure 1. History of sound limit in Japan

2. CONCEPT FOR IMPROVED SOUND MODEL

2.1 Steps to improve sound model

Updating sound model with current method needs a lot of measurements. Easier method and less workload are desired. Following steps are considered to improve sound model.

Step 1;

- Establish method of making sound model for a vehicle with proving ground test by ISO362-1 (Measurement of noise emitted by acceleration road vehicles - Part 1:M and N categories) which is commonly used.
- Gather updated sound models for key categories

Step 2;

- Make sound models based on past or future sound limits
- Simplify sound model to two formulas, tire and power train
  (Merge mechanical and dynamic formulas)

This paper covers Step1. The model can be analyzed sound behavior in detail for an individual vehicle. At Step 2, vehicle sound will be calculated from sound limit in the regulations for any vehicle category and any vehicle age, and applicable to ASJ-RTN or CNOSSOS-EU. (See Fig. 2)

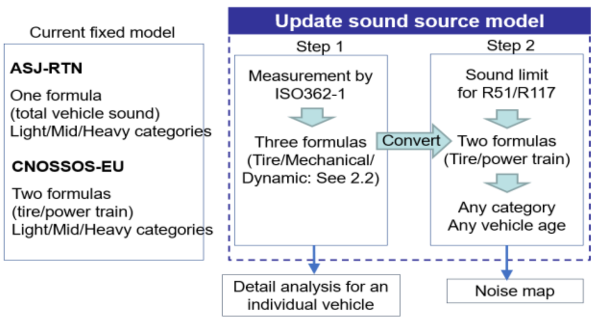

Figure 2. Concept for update of sound source model

2.2 Structure of basic formulas

Main sound sources emitted by vehicle are tire, engine, drive line, intake, and exhaust. Sound power level from sound sources depend on (engine) load condition. As shown in Fig. 3, these elements would be described in L_{TR}, L_{PT}, and L_{DYN}, which are sound power level of tire rolling sound, power train sound without load, and dynamic sound respectively. They are defined in Eqn. (1) to Eqn. (3).

$$L_{TR} = \theta_{TR} \log_{10}\left(\frac{V}{V_{REF}}\right) + L_{REF\_TR} + \Delta L_{road} \quad (1)$$

$$L_{PT} = \theta_{PT} \log_{10}\left(\frac{n}{n_{CRS}}\right) + L_{REF\_PT} \quad (2)$$

$$L_{DYN} = \theta_{DYN} \log_{10}\left(\frac{n}{n_{WOT}}\right) + L_{REF\_DNY} \quad (3)$$

where θ_{TR}, θ_{PT}, and θ_{DYN} are regression coefficients, V and n are vehicle speed and engine speed respectively, and ΔL_{road} is the correction for road surface. V_{REF} is normally 50km/h. L_{REF_TR}, L_{REF_PT}, and L_{REF_DYN} are sound power level for the vehicle determined by measurements. n_{CRS} and n_{WOT} are engine speed at maximum sound level in constant speed test and WOT test respectively.

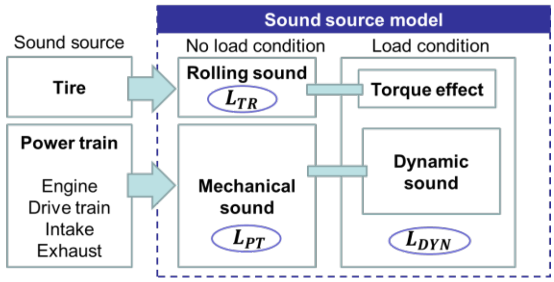

Figure 3. Structure for sound source model

3. PROPOSED SOUND SOURCE MODEL

3.1 How to make a sound model

Measurements based on ISO362-1 for M1 and N1 categories test procedure and tire free rolling test (e.g. coast down test) are needed to make a sound model. Fig. 4 shows test layout in case of acceleration test. Differences from ISO362-1 are that acceleration test shall be conducted with wide throttle condition (WOT) and one gear (or D range). Overview of the process to determine L_{REF_TR}, L_{REF_PT}, and L_{REF_DYN} is shown in Fig. 5. First, Eqn. (4) is defined from tire free rolling test with several vehicle speed conditions.

$\theta_{TR\,x}$ is determined by correlation expression at every position x.

$$L_{TR\,x} = \theta_{TR\,x}\log_{10}(V_x) + C_x \tag{4}$$

where x is vehicle position. L_{CRS_TR} is $L_{TR\,x}$ at maximum sound pressure level of constant speed test (L_{CRS}) and L_{WOT_TR} is $L_{TR\,x}$ at maximum sound pressure level of WOT test (L_{WOT}). $L_{REF\_TR'}$ and $L_{REF\_PT'}$ are determined from L_{CRS} and L_{CRS_TR} as shown in Eqn. (5) and Eqn. (6).

$$L_{REF\_TR'} = L_{CRS\_TR} \tag{5}$$

$$L_{REF\_PT'} = 10\log_{10}\left(10^{\frac{L_{CRS}}{10}} - 10^{\frac{L_{CRS\_TR}}{10}}\right) \tag{6}$$

$L_{REF\_DYN'}$ are calculated from L_{WOT}, L_{WOT_TR}, and L_{WOT_PT}. L_{WOT_PT} is calculated from Eqn. (2) with engine speed at the position of maximum sound level of acceleration test.

$$L_{REF\_DYN'} = 10\log_{10}\left(10^{\frac{L_{WOT}}{10}} - 10^{\frac{L_{WOT\_TR}}{10}} - 10^{\frac{L_{WOT\_PT}}{10}}\right) \tag{7}$$

Sound power level is converted from sound pressure level by Eqn. (8).

$$L_{REF\_j} = L_{REF\_j'} + 8 + 20\log_{10} l \tag{8}$$

where j is TR, PT, and DYN, and l is distance between microphone and center line on test track, $l = 7.5m$.
θ_{PT} is determined by no load sweep test with engine speed variation. $\theta_{DYN} = \theta_{PT}$ are considered based on data.

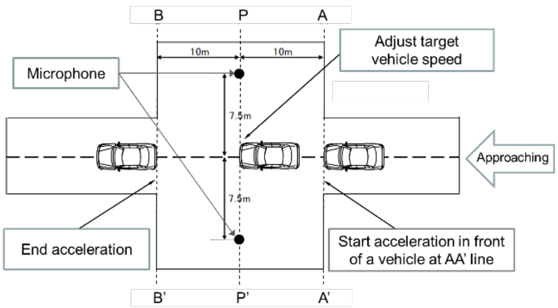

Figure 4. Layout for pass-by noise measurements

Vehicle sound power level is calculated by Eqn. (9)

$$L_{W\_Total} = 10\log_{10}\left(10^{\frac{L_{TR}}{10}} + 10^{\frac{L_{PT}}{10}} + X \cdot 10^{\frac{L_{DYN}}{10}}\right) \tag{9}$$

where X is load factor defined acceleration rate during test divided by acceleration rate in WOT condition.
In case of EV or HEV without engine operation (only electrical motor driving), Eqn. (10) is used.

$$L_{W\_Total} = 10\log_{10}\left(10^{\frac{L_{TR}}{10}} + X^m \cdot 10^{\frac{L_{TR\_TRQ}}{10}}\right) \tag{10}$$

where L_{TR_TRQ} is torque effect for tire noise during acceleration and additional measurement is needed to define the value. m=3 is used based on database.

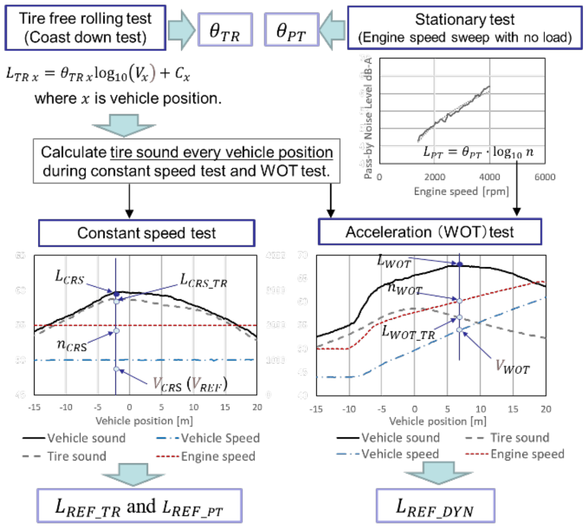

Figure 5. Process to determine coefficients

3.2 Validation for proposed sound source model

For validation, comparison between measured result and calculation of proposed sound source model is examined with pass-by noise on test layout in Fig. 5. The sound source model is applied to two passenger cars, vehicle 1: petrol engine with CVT (continuous variable transmission) and vehicle 2: series HEV.
Fig. 6 shows pass-by noise level at 7.5m from center line measured and calculated with Eqn. (9). Test condition is 50km/h at PP' line and WOT, and 40km/h at PP' line and 50% throttle opening. As a result, the calculated results for both of vehicle 1 and vehicle 2 consist with measured data. Even if the sound model is made from only 50km/h WOT test and constant test data, different vehicle speed and throttle opening can be predicted.

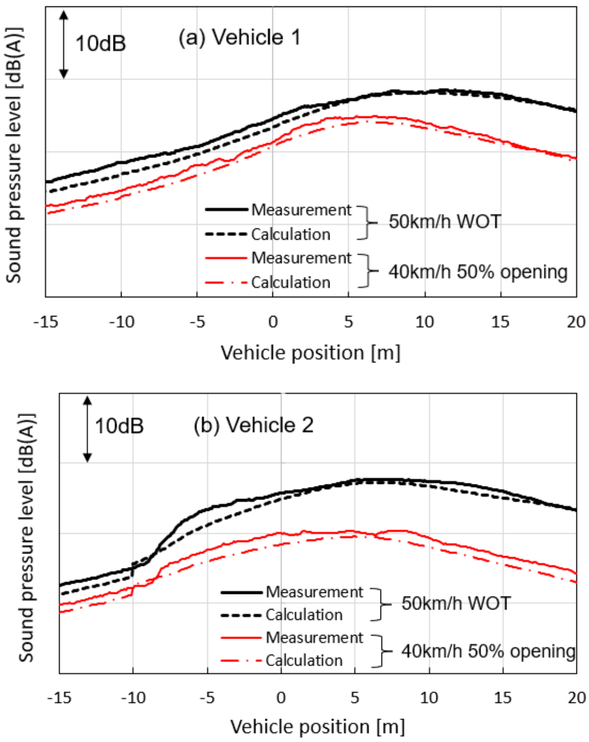

Figure 6. Comparison between measurement and calculation

3.3 Application example

The sound model can provide predicted sound power level from a vehicle with any vehicle conditions. Fig. 7 shows an example of prediction of sound power level for a passenger car at urban driving condition which is defined by vehicle speed, engine speed, and acceleration. Tire sound is dominant mostly but higher acceleration may cause higher power train sound (mechanical sound and dynamic sound).

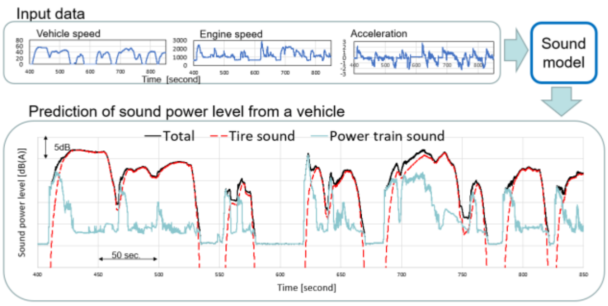

Figure 7. Example of sound power level prediction

4. CONCLUSION

Vehicles with old certification (old sound limit) as well as the latest certification are combined in actual traffic flow. In addition, vehicle noise regulation and tire noise regulation are not synchronized. Therefore, new concept would be useful since updating sound model accordingly will be faced difficulty future. Proposed sound model can be made with less data and good correlation with experimental data are shown. Discussion for next sound limit in the regulation is started, then prediction of road traffic noise would be more important. Proposed sound model would be expected.

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