Comparison of pass-by noise from real track and simulated measurement at the roller test bench

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ABSTRACT

The type approval of motor vehicles according to ECE R51 is performed on standardized road surfaces and under defined conditions. The type test takes place in the open air and is highly dependent on the local weather conditions. The Fraunhofer Institute for Building Physics IBP operates a four-wheel drive dynamometer where this measurement can be simulated in a semi-free field acoustic environment. Influences, such as the modified foot print of the tires, the surface of the roller and the floor, cause divergences to the pass-by measurements performed on the test track. Today the standard ISO/FDIS 362-3 for measurement of pass-by noise levels in test halls is emerging. There, the method A describes a procedure combining a simulated pass-by (drive train noise component) and real pass-by (tire rolling noise component). With a validation procedure the precision of such a simulated pass-by in the test rig may be compared with a real pass-by on a test track. Such validation was performed between a real test track and the four-wheel drive dynamometer at Fraunhofer-IBP. The procedure, the essential factors and the results of the measurements are presented and evaluated.

Keywords: Pass-By, Simulated measurement, Roller Test Bench, Fraunhofer

I-INCE Classification of Subjects Number(s): 11.7.1

1. INTRODUCTION

The type approval measurements of motor vehicles according to the EC type-approval procedures for compliance with legal noise limits for vehicles is carried out under defined conditions according to ISO 362-1 (1). This real vehicle pass-by measurement is performed on a standardized outdoor noise measurement track and is highly dependent on the local weather conditions. It stands to reason, to transfer the outdoor measurement in a test chamber with the possibility to simulate the pass-by of vehicles. The Fraunhofer Institute for Building Physics operates a four-wheel chassis dynamometer since 2008, in which the simulated pass-by can be performed in an acoustically semi-anechoic room (2, 3). The advantages of the indoor measurement method are the constant measuring conditions and the weather independence. Due to the altered footprint of the tire, the surface of the roller and the surface of the floor of the test-chamber, there are significant acoustic differences to an outdoor pass-by measurement.

Recently, a final draft of the ISO 362-3 (4), indoor testing of noise emitted by accelerating road vehicles, has been published. The Standard describes a method as a combination of the measurement of the powertrain noise (PTN) on the dyno (comparable to ISO 362-1) and the energetically addition of the tire-road noise (TRN), which is measured on an outdoor test track. With a validation method in (4), the accuracy of the simulated pass-by measurement (indoor) can be confirmed by comparison with a pass-by test (outdoor) on a test track. Such a validation method was performed between a real test track and the 4-wheel chassis dynamometer at the IBP.

Four vehicles that differ in their drive concept and performance class were used for the experimental study (5). Among them are two compact cars, each one with front (VW Golf) and

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rear-wheel drive (BMW 116D), a hybrid vehicle with front wheel drive, which is operated purely electrically during pass-by (Opel Ampera), and a four-wheel drive sports car (Porsche Carrera 911).

2. Pass-by measurement according to DIN ISO 362-1 (outdoor)

The measurements of pass-by noise are carried out on a test site which meets the requirements of ISO 10844 (6). Figure 1 shows the dimension and the setup of the test track. The measuring range extends from the perpendicular lines AA to BB. To record the level of passing vehicles, a measurement microphone is positioned on the left and the right side of the vehicle travel line CC in the middle of the test track between AA and BB.

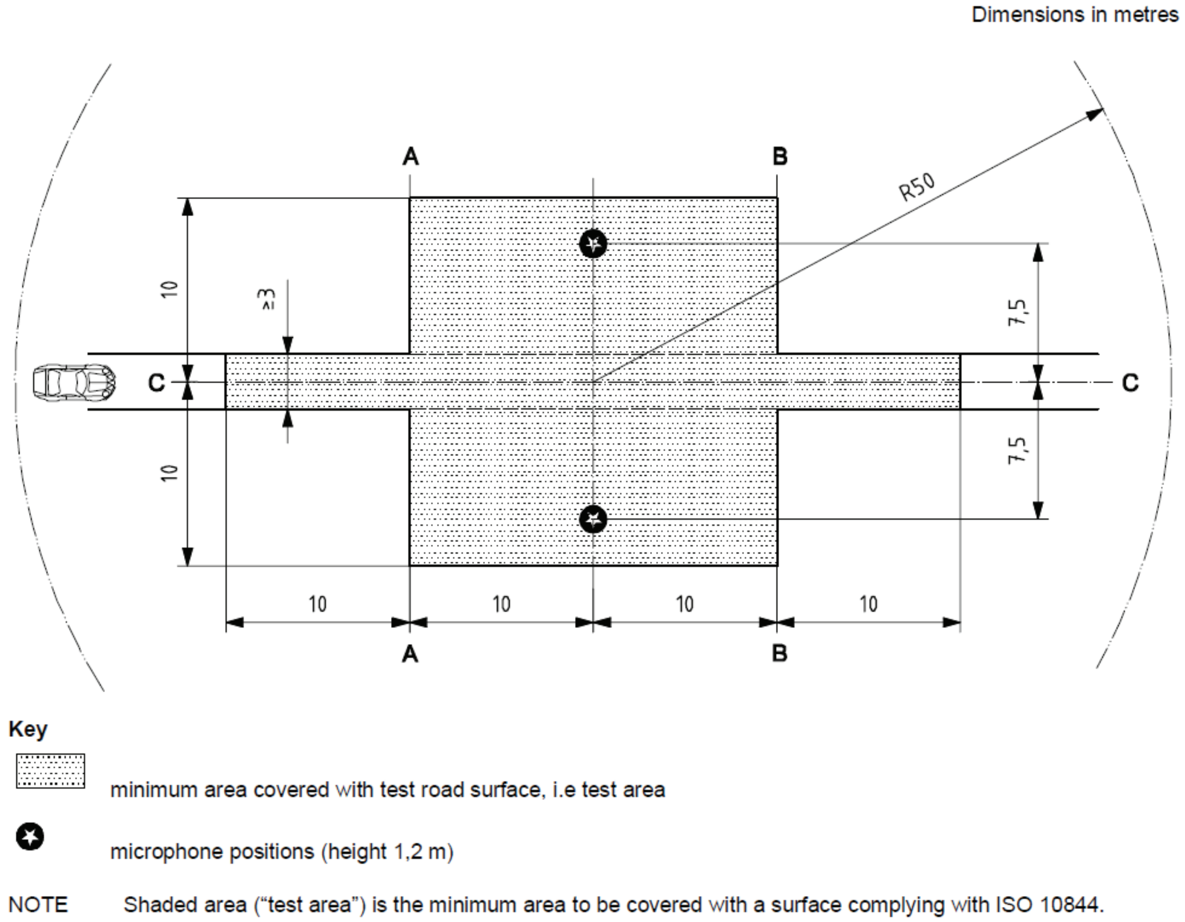


Figure 1 – Dimensions of the test track for the pass-by measurements according to DIN ISO 362-1 (1)

The reported vehicle sound pressure level L_{Urban} is a calculated value, representing an urban operation of a vehicle. The vehicle sound pressure level is a composite of an accelerated $L_{wot\ rep}$ and a constant pass-by measurement $L_{crs\ rep}$ which considers the target acceleration a_{urban}. The target acceleration of the test vehicle again is calculated from the dimensionless power-to-mass ratio index (PMR) and is representing the urban traffic acceleration. The aim of accelerated pass-by measurement is to reach the reference acceleration $a_{wot\ ref}$. Therefore, the appropriate gear constellation must be found before starting the measurements. Additionally, the test speed at AA must be chosen such that a speed of 50 km/h ± 1 km/h is reached at the center of the test area. During the acceleration test, the accelerator pedal shall be fully engaged when the front of the vehicle reaches AA and held fully engaged until the rear of the vehicle reaches BB. The constant-speed tests are carried out with the same gears used in the acceleration test. There are four passes to be driven, in each gear to be tested and for each side of the vehicle. The first four successive measurement results that differ less than 2 dB may be used to calculate L_{urban}.

3. Simulated pass-by according to ISO/FDIS 362-3 (indoor)

The measurement of the vehicle pass-by sound pressure level on an outdoor test track can be transferred into a semi-anechoic chamber with comparable dimension, a 4-wheel chassis dynamometer and suitable measurement technology. The vehicle is fixed in its position on the roller test bench for the indoor measurement. Similar driving resistances for the vehicle, as if on a real road, are set in a so called road simulation provided by the control of the roller bench. The simulated pass-by level is calculated on a computer from multi-channel recordings of two linear microphone arrays, where a time signal is synthesized that is consistent with a conventional pass-by measurement according to ISO 362-1.

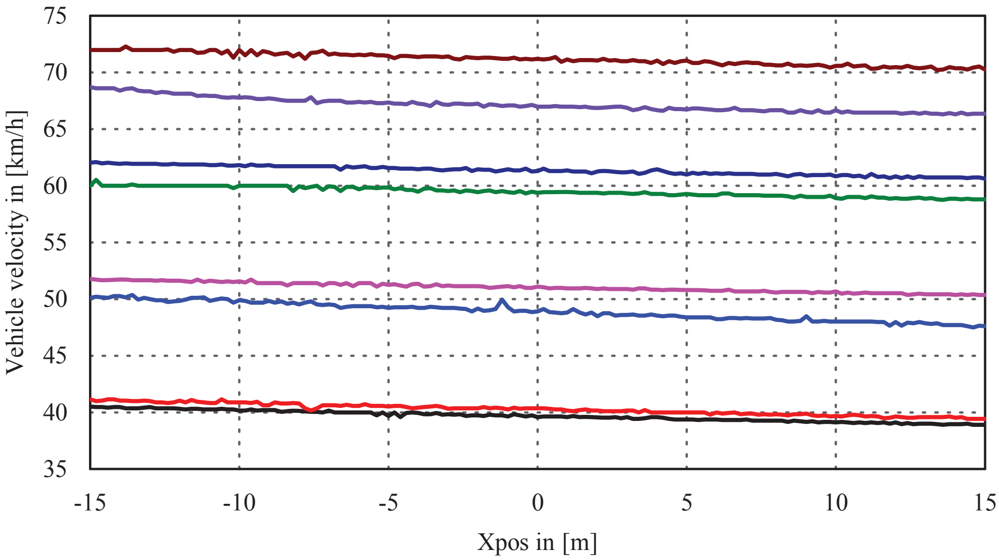
The basis for the synthesis is an accurate sound level measurement for simulated pass-by where the sound field of the vehicle is detected with correct distance and almost gapless by a number of microphones. This measurement method requires small distances between the microphones and a corresponding multi-channel and powerful measurement technique for time-synchronous recording of all signals. The passing is simulated by the sound pressure levels, which are successively used from two adjacent microphones. In addition, a synchronously recorded speed signal from the roller rotation is provided in order to produce an unambiguous correlation to the microphone signals.

3.1 ISO/FDIS 362-3, Variant A

Variant A of ISO/FDIS 362-3(4) describes a measurement procedure in which the noise component of the exhaust and the powertrain is determined separately from the tire rolling noise component of the vehicle pass-by. The indoor measurement procedure determines only the noise portion of the exhaust and powertrain noise (PTN). The share of the rolling noise (Tire Road Noise (TRN)) is determined separately. Both noise contributions are summed energetically and result in the total vehicle noise level (TVN). The calculation is performed separately for each side of the vehicle and at every position x on the measuring track. In order to detect only the noise level of the powertrain of the vehicle, the tire rolling noise must be suppressed as much as possible. For this purpose, slick tires without tire tread are appropriate. In order to minimize the TRN on the dynamometer during the measurements, it is recommended to use the least possible number of driven axles.

The TRN used for the simulated pass-by is calculated from a previously determined characteristic diagram of the tire, the driving speed and the acceleration. The tire characteristics consists of a data record and regression coefficients α(x) and β(x), which are determined on a standardized exterior noise test track. The driving speed and the acceleration are recorded during the simulated pass-by on the bench. The calculation of the TRN is made up of two components, the Free Rolling Noise (FRN) and the Torque Influence (TI)) of the tire under load.

The tire characteristic of the FRN is described using a logarithmic regression model. As input data emitted tire rolling noise of passing vehicles on the real exterior test track is used. For this purpose, the tire noise at different speeds, and as a function of track position, are recorded analog to ISO 362-1 (see Figure 2).



Figurer 2 – Example of speed profiles for creating a tire characteristics diagram

In order to suppress the exhaust and powertrain noise in the measurement, a special enclosed vehicle is advantageous. Alternatively, a vehicle with a combustion engine may be used. Here, the vehicle must be disengaged and the engine stopped during pass-by.

Using the regression coefficients, it is possible to calculate the tire noise $L_{FRN(x\ v)}$ for each velocity, anywhere between the lines AA and BB. From the determined regression coefficients a tire characteristics diagram for a type of tire can be created (matching the type of vehicle) on an exterior test track.

The standard proposes a simplified calculation for the torque component determination of the TRN. The calculation is again dependent on the acceleration and the position of the vehicle on the test track. This formula includes a coefficient ζ that can take different values for each exterior test track.

Alternatively, the standard proposes a more accurate method for determining the torque influence, which has not been applied in the current study, since an encapsulated vehicle is essential in this case. In order to ensure proper transmission of the TRN of the exterior test track to the test bench, a temperature correction must be applied to the level of the TRN.

3.2 Validation according ISO/FDIS 362-3 (Variant A)

The test method for "Variant A" is divided into two measurements, a so-called main and a validation measurement. The main measurement was carried out according to ISO 362-1 on the exterior test track. The validation measurement is the measurement on the four-wheel chassis dynamometer with pass-by measuring hall according to variant A. Main and validation measurements are compared, the main measurement is the reference. The validation measurements must not deviate by more than ± 1 dB from the reference. More tolerance thresholds exist concerning the temperatures at the air intake (± 5 °C), the CAT/diesel particulate filter (DPF) and end muffler (± 15 °C), the engine speed (± 2 %) and the vehicle speed (± 1 km/h).

4. Results

Figure 3 shows as an example of the validation result of the accelerated pass-by of the BMW 116d. The level difference between the TRN and PTN is small in the range between -5.0 m and +5.0 m. For the remaining track positions TRN becomes more dominant. Only small deviations were found for TVN comparing the main measurement with the validation measurement. The levels on both sides of the vehicle are on the complete path within the required tolerance of the validation.

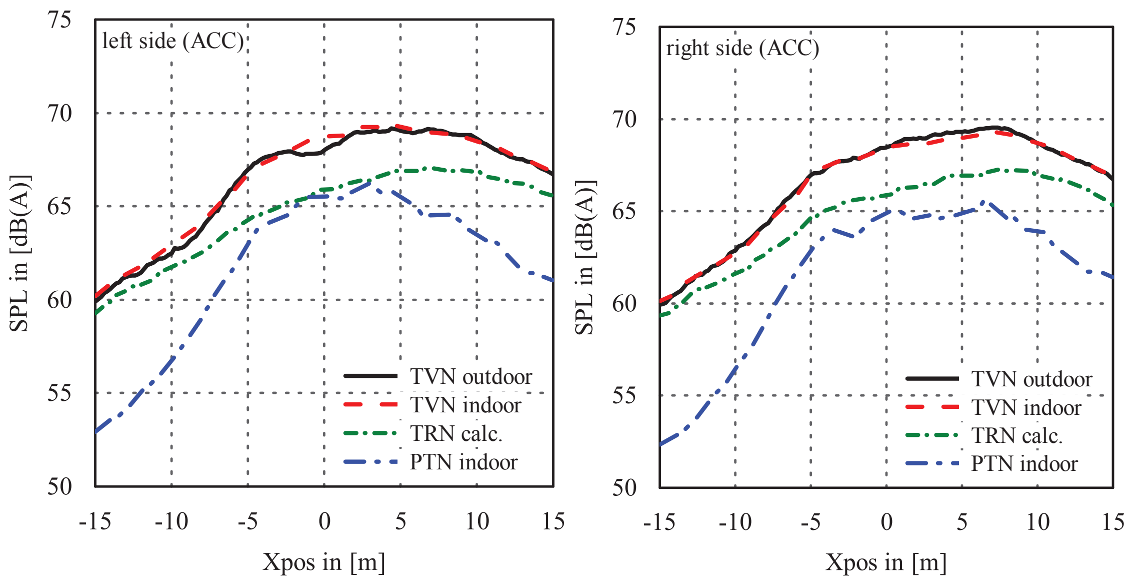


Figure 3 – Final results for the type test method according to Variant A of ISO/FDIS 362-3 - representation of accelerated pass-by (mean value run 1-4) of the respective left and right side of the BMW 116d.

Figure 4 shows validation results of the constant speed pass-by of the BMW 116d. Unlike the accelerated pass-by the noise level of the powertrain PTN is well below that of TRN. On the left side of the vehicle the noise of the powertrain increases the overall noise by +1.3 dB. On the right side of the vehicle the noise portion of the powertrain raises the overall vehicle level by 1.0 dB. Thus, the level contribution of the powertrain on L_{TVN} is rather low. The TRN is the dominant noise source at the constant speed pass-by. The comparison of the real to the simulated pass-by shows on the right side of the vehicle hardly any differences. The maximum deviation is 0.4 dB. At the left side of the vehicle, there is a maximum difference of +0.6 dB.

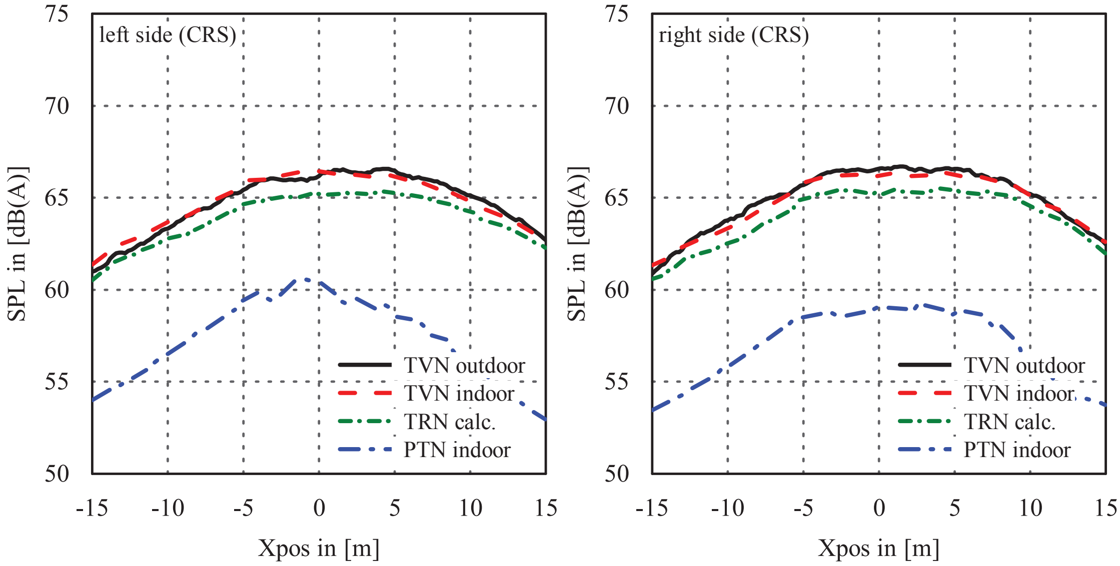


Figure 4 – Final results for the type test method according to Variant A of ISO/FDIS 362-3 - representation of the constant speed pass-by (mean value run 1-4) of the respective left and right side of the BMW 116d.

The measurements of velocity in Figure 5 reveal only little variation and are within the tolerance range. Regarding the measured rpm at the BMW 116d an increasing spread of the rpm curves can be seen. The rpm indoor on the test bench shows an increasing deviation along track position to the rpm of the real pass-by, with a maximum deviation of 84 rpm at +13.0 m. This corresponds to a deviation of 4.1 % that is 2.1 % higher than the maximum positive tolerance. The deviation is caused by the different measurement systems that had to be used.

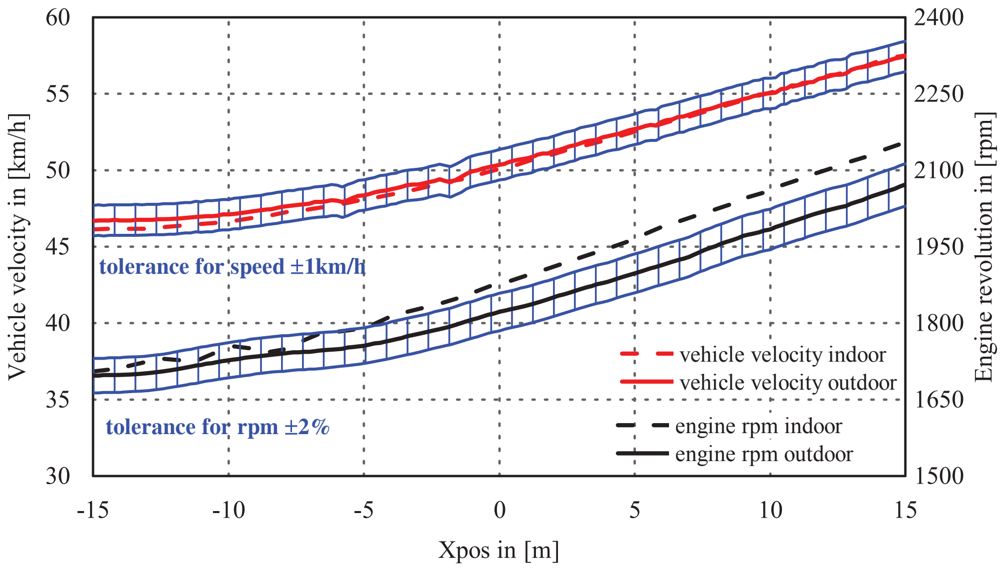


Figure 5 – Examination of speed and rpm for conformance with required tolerances for validation according to Variant A of ISO/FDIS 362-3 of the BMW 116d.

Table 1 shows the measurement results for the BMW 116d. The mean test accelerations differ by about a tenth. This may be caused by slightly different entrance or exit speeds between real and simulated pass-by. There are small differences in partial power factor kp, which is necessary for calculating of the type approval level L_{urban}, that are caused in deviations of the mean test acceleration a_{wot}. The difference between the type approval levels L_{urban} is 0.4 dB.

Table 1 – Results of calculation for type approval level L_{urban} for the BMW 116d between real and simulated pass-by

Single results	ISO 362-1	ISO 362-3
Gear	3	3
a_{wot} [m/s²]	1,66	1,75
L_{wot} [dB(A)]	69,6	69,4
L_{crs} [dB(A)]	67,0	66,5
L_{urban} [dB(A)]	68,6	68,2

The measured temperatures of the air intake and the exhaust end muffler of the BMW 116d are within the tolerance range. The comparison of the DPF temperatures between outdoor and indoor measurement shows that the tolerance is exceeded by ±15 °C. An increase in temperature during the simulated pass-by reveals that the vehicle has not been sufficiently warmed up.

The formula used for the portion of the torque influence depends on the indoor acceleration and the coefficient ζ. This coefficient describes substantially the contribution of torque influence on the pass-by noise level on the exterior test track. The coefficient can take values from 0.075 to 0.15, and represents the "loudness" of the exterior test track. Figure 6 indicates calculated pass-by level on the left side of the Opel Ampera for the minimum and maximum value of coefficient ζ. Due to the high (non-standard) acceleration value of more than 4 m/s², the proportion of torque influence reaches partially 3 dB.

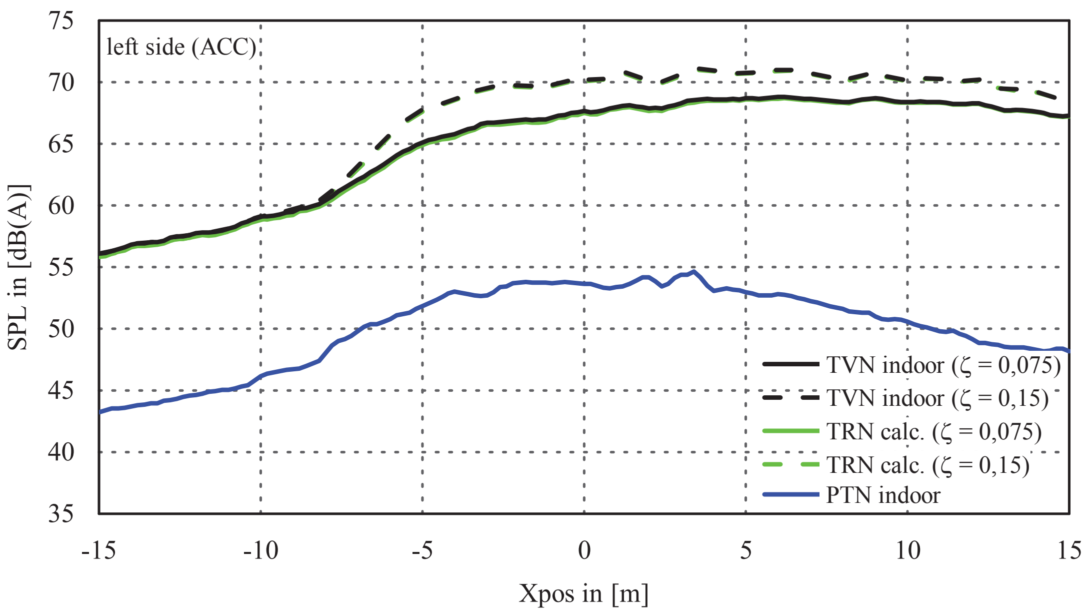


Figure 6 – Extremes of coefficients ζ for calculation of TRN - Opel Ampera, run 1, ACC, left

With accelerations according to the standard of max 2 m/s² this varies only between 0.8 and 1.5 dB. A coefficient of 0.075 was used as best fit for the exterior test track employed for the experiments. The further validation results of type approval level for real and simulated pass-by are listed in Table 2 below. The levels differ only slightly for all vehicles and are within the tolerances of the validation.

Table 2 – Results of calculated type approval level L_{urban} for the remaining vehicles between real and simulated pass-by in dB(A). *a_{urban} > 2 m/s²

Vehicle	VW Golf V		Porsche 911		Opel Ampera	
Side	Left	right	Left	right	Left	right
Outdoor	68,8	**68,8**	**74,7**	74,5	**66,3***	66,1*
Indoor	68,3	**68,7**	74,7	**74,9**	**66,4***	66,2*
Delta	0,1		0,2		0,1	

5. Summary

The results of the study show that the comparison between real and simulated pass-by has led to a good agreement. The required tolerances within the validation were met for all vehicles. In the determination of auxiliary variables, such as temperature or rpm, small variations were partially observed for the tolerance range to be maintained. The comparison of type approval level L_{urban} revealed only very small deviations for all vehicles. The differences for the Opel Ampera and VW Golf V are at 0.1 dB, for the Porsche 911 at 0.2 dB and for the BMW 116d at 0.4 dB.

The tolerances of validation are set very close under the current state of the ISO/FDIS 362-3. Despite the high accuracy in conducting the comparison of real and simulated pass-by, variations in the results for some criteria, such as temperature or rpm, have arisen. Nevertheless, the type approval level was always within the permissible range. This leads finally to the conclusion that in the described implementation, an application of the simulated pass-by on the dynamometer is possible.

One approach for improvement would be the exact determination of the torque effect on tire noise by means of a quadratic regression procedure, which could help to determine the coefficient ζ exactly. The ISO/FDIS 362-3 describes this in Annex B, chapter 3.2 and 4.3, how such a method may be carried out. For the necessary measurements of the velocity profile, a tire test vehicle with noiseless powertrain is mandatory.

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