Method for Scaling the Indoor Pass-by Noise Testing on a Roller Test Bench in a Small Anechoic Chamber

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Abstract- The pass-by noise is a necessary validation step within the vehicle development process for the homologation of every vehicle. With respect to accuracy and reproducibility and to avoid for example weather conditions etc. there is an effort to transfer the pass-by noise measurement into an acoustic roller test bench. Therefore an acoustic chamber in the size of the ISO 362 track is obligatory. Those chambers are very expensive and often not possible because of the facility's infrastructure.

The anechoic chamber at IPEK – Institute of Product Engineering at KIT includes a four-wheel roller test bench but is not providing the ISO 362 track dimensions. In order to measure the complete length of the test track in small chambers it is necessary to develop a method for scaling the measurement setup. In this contribution the focus is the scaling from large to small chambers and not the transfer from road to rig itself.

To quantify related influences the paper at hand deals with measurements by the use of generic sources, for example a full and a half dodecahedron and discusses the results. These results are transferred to the vehicle application in order to get valid and reproducible results.

Keywords- Acoustic; Indoor Pass-by; Anechoic Chamber; Dodecahedron

I. INTRODUCTION

Vehicles are multidisciplinary and highly complex systems. Therefore it is essential to develop new methods for the engineering process and especially for the validation. The quality of the vehicle and with it the buying decision are not only influenced by fuel consumption or durability but also by the acoustic comfort. The Noise-Vibration-Harshness (NVH) behaviour of vehicles gets more and more importance in this context. Not only vibration and noise for the passenger has to be considered but also the noise emitted by driving the vehicle on the road.

For the homologation a specific domain in context of NVH and especially the acoustics is the pass-by noise measurement. Today the certificated measurement of the pass-by noise is only allowed on the test track. Because of the increasing complexity of the drive-train system, especially for hybrid systems, and with it a complex driving and operation strategy it is just a question of the time that the measuring manoeuvre cannot be handled by a real driver. Also the necessary space for the test areas is expensive and emitting noise disturbs the environment. To avoid waiting time and delays in the vehicle engineering process due to bad weather, and in order to measure with a higher reproducibility, there is an effort to transfer this measurement from the test track to the roller test bench [1].



Fig. 1 Test track according to the ISO 362 guideline [2]

In the ISO 362 guideline first approaches are defined to specify the necessary roller test bench and the requirements to the anechoic chamber. The specification to the size must be at least in the length of 20 meters additional to the vehicle length and half of the under cut-off wavelength. The width must be at least 7.5 meters additional to a quarter of the under cut-off wavelength to one side.

To measure the pass-by noise on the test track two microphones are positioned in the middle of the track in a distance of 7.5 meters in a height of 1.2 m shown in Figure 1.

II. INDOOR PASS-BY NOISE TESTING IN THE CONTEXT OF XIL

For the validation Albers [3] developed the so-called "X-in-the-Loop Framework (XiL)", as shown in Figure 2.

This framework describes a validation framework according to the development of electronic devices. The Unit Under Test is always considered in context of the System Driver, System Environment under realistic or generic Manoeuver and Test Cases to close the control loop of testing. The Unit Under Test can be in different layers, for example the clutch, the clutch with the complete gearbox, the powertrain by itself or the complete vehicle and can be accomplished always with a specific suitable (more or less detailed) Rest Vehicle Model.



Fig. 2 XiL-Framework [3]

For the simulated indoor pass-by noise testing the main focus of the paper at hand is on the systems environment and the driver. The environment must suffice a 50-meter radius free field condition and as mentioned above the test track and the anechoic chamber must be at least 20 by 20 meters. The microphone positions must be 7.5 meters away from the centre line, so it is positioned in the far field. Additionally there must be remaining space between microphone and acoustic housing, depending on the measured frequencies.

While running the manoeuvre on the roller test bench the sound of the vehicle is recorded with an array of 1/2" free-filed microphones of the type G.R.A.S. 46AE positioned in 7.5 m distance and 1.2 m height referring to the guideline as it is usual in the state of the art. After the run the microphone signals are calculated by crossfading the signals depending on the virtual position on the test bench to a virtual pass-by result. According to the state of the art the vehicle can be simulated as a point source located on the bottom positioned in the middle of the vehicle's combustion engine (see Figure 10).

The roller test bench at IPEK – Institute of Product Engineering is in a semi anechoic chamber which is smaller than that specified in ISO standard. Therefore it is necessary to develop a method for scaling the measurement with a microphone array in the free field.

III. SCALING TO SMALL ANECHOIC CHAMBERS

State of the art describes a method for scaling the setup to small anechoic chambers. The method enables the measurement of the complete track in a chamber which is smaller than the ISO required. As well as the standardized indoor pass-by measurement these methods are based on four basic assumptions:

- the measurement environment is a free field(1);
- the microphones are placed in the far field(2);
- the vehicle can be simulated as a point source(3);
- the acoustical centre of the point source is placed in the middle of the engine at the bottom(4) [4].

While reducing the distance between the array and the vehicle state of the art adapts the microphone height by linear scaling (with respect to assumption 1). That means the quotient of the distance and the microphone height must be the same as described in the ISO guideline, shown in Figure 3.



Fig. 3 Array in different distances to scale the measurement track [3]

The sound pressure is calculated to the original distance by the law of the free field condition, which means that the sound pressure is indirectly proportional to the distance between source and microphone (Figure 6: red line).

With these assumptions some measurements were done and the results are shown in Figure 4. It is possible to scale up the test track in small chambers, but there is a displacement in the maximum of the sound pressure level in two directions. On the one hand the maximum increases and on the other hand it is shifted in vehicle driving direction. The deviation is over 4 dB(A) and with it over the defined tolerance of 1.4 dB(A) according to ISO.



Fig. 4 Measurement results with different distances between vehicle and array

Based on theoretical considerations there is the hypotheses that at least one of the assumptions is not acceptable. To identify which is not correct, some measurements were done by simulating the vehicle as a half and a full dodecahedron.

IV. MEASURING WITH GENERIC SOURCES

To validate the minimal distance and the free field condition (Assumptions 1 and 2) measurements with a half dodecahedron were done, as shown in Figure 5. The generic noise was on the one hand white noise and on the other hand a recorded sound from a vehicle.



Fig. 5 Scaled measurement results with the half dodecahedron

The results of the scaling are very accurate so the far field and the free field conditions are given and it is possible to scale the sound pressure from the microphones with the law of the free field. So assumption 1 and 2 are valid.

In the next step the vehicle is simulated as a point source above the ground level with a full dodecahedron. The difference with the before mentioned measurements is that the dodecahedron has a 360 degree emitting characteristic. With that there are additional reflections from the chamber's floor.

There is some research on positioning the microphones based on the same interference in very small distances, which is not relevant for passenger cars. The frequency analysis shows that interferences do not influence the results, due to the processing of the complete spectrum. One constructive or destructive interference frequency has not any influence to the sound pressure level calculated over the complete spectra.

For sources above the ground a new method for calculating the microphone height is discussed, as shown in Figure 6 (green line). It is based on the same angle, so on the one hand the directional characteristic is covered and on the other hand the source height is covered [5].



Fig. 6 New method for the positioning the microphones

Using this calculation, new measurements were done and compared to those with the linear scaling on the microphone height, shown in Figure 7.



Fig. 7 Measurement results with the linear source height based calculation

The results with the linear microphone scaling show the same behaviour as the measurements in the state of the art with the vehicle. The new method instead shows good scaling results. This is caused by the dominating sound pressure of the direct sound path instead of the reflected. This is due to the sound absorption of the bottom and the longer passed distance of the reflected path. So it is more important to consider the direct noise path according to the source height than the interference between the direct and the reflected noise path. It is important to know the height of the source so that the microphone height can be calculated by the same angle.

For the measurements mentioned above the source was always placed in the point of origin from the microphone array, so the maximum of the sound pressure level is always in the same position. Placing the source out of the origin the maximum moves by the scaling in one direction, shown in Figure 8.



Fig. 8 Measurement results with an eccentric placed source

This results from the wrong projection of the microphone position, if the maximum of the sound pressure level is correlated to the specific virtual way. In Figure 9 there are two positions demonstrated. If the source is in position A the maximum would be in every three cases in the middle. But if the acoustic centre is in the position B the maximum is projected at 7.5 m correlating to the way to a wrong position.



Fig. 9 Geometric projection of the scaled sound pressure level

So in conclusion it is not only necessary to know the height of the source, but also the position of the source in the longitudinal direction of the vehicle.

The complete vehicle consists of different dominating sources, like the engine and the front and rear wheels. To identify the position of the virtual acoustic centre there are different methods to measure these sources, for example the transfer path analysis or with an acoustic camera. These methods are very complex and time-intensive just for identifying the positions. Therefore a new method is obligatory.

The transfer path analysis shows that the sound pressure level of the tyres and the engine is nearly the same. It also can be shown that the tyre noise is not only emitted in the road contact surface. There are also effects which excite the complete tyre [6]. The noise emission is also influenced by the geometric form of the wheel case. Respectively the tyres are also simulated as a source, but in the middle of the wheel hub.

Out of this, three dominating sources – according to the formula for the centre of gravity – the acoustic centre can be calculated. Every source is like a mass and the position of it is the lever. With a weighting of the sources depending on each sound pressure level, a total position of the acoustic enter can be defined. Taking a closer look at a combustion driven vehicle there are three dominating sources, shown in Figure 10. So the calculated position is not anymore on the bottom and more backward than the old position in the state of the art and with it the Assumption 3 is valid but the vehicle is not a point source on the bottom any more (s. Assumption 4).



Fig. 10 Vehicle with the dominating sources

V. VALIDATION OF THE NEW CALCULATION

In the following chapter the new method is validated using the same vehicle like in Chapter III. As mentioned the acoustic centre is now in the calculated position. The microphone height was calculated by the same angle according to the position of the calculated source centre.

As shown in Figure 11 the scaled results are very accurate with a tolerance of 1.1 dB(A) that is in the guideline tolerance limits of 1.4 dB(A). The new method shows that it is possible to scale the measurement setup in small anechoic chambers, by scaling the microphone height based on the same angle. Herewith, the knowledge of the position of the acoustic centre is mandatory in order to avoid deviations and to increase accuracy.

This method was validated at two more vehicles from different categories. On the one hand a SUV, as a very high vehicle and on the other hand a compact car as a small one with different combustion types. On both systems the scaled results provide the required accuracy as well.



Fig. 11 Indoor pass-by with the new calculated microphone height and position

VI. CONCLUSIONS

In this contribution a new approach is shown for measuring the pass-by noise in an anechoic chamber that is smaller than guideline specifications. Therefore the measurement setup, based on a microphone array in the far field was scaled.

Based on measurements from the state of the art systematic deviations were identified. On the one hand the maximum of the sound pressure level increases and on the other hand it moves in longitudinal direction with the reduction of the distance between microphone array and vehicle centre line. For identifying the deviations the indoor pass-by measurement was discussed in the context of the XiL-Framework and measurements with generic sources were done.

The measurement with the half dodecahedron shows good results, so the free field condition is given and the array is positioned in the far field.

The results with the full dodecahedron as vehicle's point source above the ground show the same characteristic as the measurements with the vehicle. Therefore a new calculation for the microphone height based on the source height was developed. Furthermore a method for easy calculating the position of the acoustic centre was shown.

The new method was validated using different vehicles from different classes.

For the next step the tyre influence is to be investigated in order to gain accuracy as well as sensitivity for the calculated acoustic centre. Furthermore, the method is to be transferred and validated on hybrid vehicles as well as on larger vehicles and chassis styles.

REFERENCES

- [1] A. Albers, and G. Robens, Indoor Pass-by noise testing on a roller test bench in a small anechoic chamber, Internoise, Osaka, Japan 2011.
- [2] DIN ISO 362-1:2009, Messverfahren f
 ür das von beschleunigten Straßenfahrzeugen abgestrahlte Ger
 äusch Verfahren der Genauigkeitsklasse 2 – Teil 1: Fahrzeuge der Klassen M und N (ISO 362-1:2007 + Kor. 1:2009).
- [3] Albers, A., and Düser, T., Implementation of a Vehicle-in-the-Loop Development and Validation Platform. In: FISITA World Automotive, Congress. Budapest, 2010.
- [4] Janssens, K., Aarnoutse, P., Gajdatsy, P., Britte, L., Deblauwe, F., and Van der Auweraer, H., Time-Domain Source Contribution Analysis Method for In-Room Pass-By Noise, 2011 SAE International, Detroit 2011.
- [5] Robens, G., Albers, A., and Behrendt, M., Indoor Pass-by noise testing on a roller test bench in a small anechoic chamber with an isotropic source, Internoise 2012, New York City, USA 2012.
- [6] Genuit 2010: Genuit, K., Sound-Engineering im Automobilbereich, Methoden zur Messung und Auswertung von Geräuschen und Schwingungen, Springer-Verlag Berlin Heidelberg 2010.



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