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Development of low noise tyres in EC project SILENCE

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In this paper the results from the development of low noise tires in the EC project SILENCE are reported. Starting with the state of the art knowledge of a leading tire manufacturer the existing ideas for further lowering the tire/road noise on surfaces used in urban areas were collected by literature research, benchmarking results and evaluation of internal experiments. As all published ideas were tested at Continental in the past and as there was no real new idea to build a low noise tire, some of the existing ideas for lowering the noise were chosen in the project. To find constructions with significant less sound radiation 22 experimental tires were constructed. In order to find the noise reduction potential of the constructions tests on a dyno drum were made. The tires of the last loop were further evaluated at the BASt on the PFF. These tires which are optimized for the surfaces defined in another subproject were at the end of the project tested in Copenhagen. The main finding that a low noise tire must have a soft tread compound and a heavy and soft belt construction was proved on all surfaces.

1 Introduction

In the last two decades a lot of efforts were made to lower the tire/road noise. The road industry has started to use open porous asphalts instead of the common stone matrix asphalts, the tire industry has optimized the tread pattern so that nowadays the radiated sound pressure of a tire in the far field is only about 1 to 5 dB(A) higher than of a blank tire with same construction. But even with these improvements the tires are at higher speeds the main sound sources of a vehicle.

If the tire industry will be able to lower the radiated sound down to the level of a blank tire by tuning the construction, this will be not enough to significantly lower the traffic noise. But neither with regulations nor with measurements can tire/road noise be reduced. First of all the noise source mechanism must be understood. For many years tire manufacturers have been searching for a construction, which fulfils the targets of the automotive industry and generates less noise.

The general objective of a work package in the EC project SILENCE was to provide design solutions as well as hardware solutions for noise reduction, with respect to vehicle/tire/road integration, under typical urban and suburban traffic conditions. This improvement is based on increased understanding of noise generation and radiation mechanisms gained by further development of experimental and simulation techniques.

2 Prototypes of low noise tire constructions

2.1 Tire/road noise mechanisms

The surface of a road is not completely smooth and has a wavelength, which differs from 50 m to less than 5 µm. The exterior noise of a tire is mainly excited by the macro roughness of the road. In the contact patch the tire is excited by the roughness of the road and this excitation leads to surface vibrations of the tire.

Depending on the tread design also the beat of tread blocks and tread blocks snap out gives additional excitation of surface vibrations. Air pumping and groove resonance are additional noise sources, which radiate normally less noise than the surface vibrations (figure 1). From our understanding the surface vibrations are the main noise source and the radiated noise in strongly influenced by the mass and stiffness distribution in the tread band.

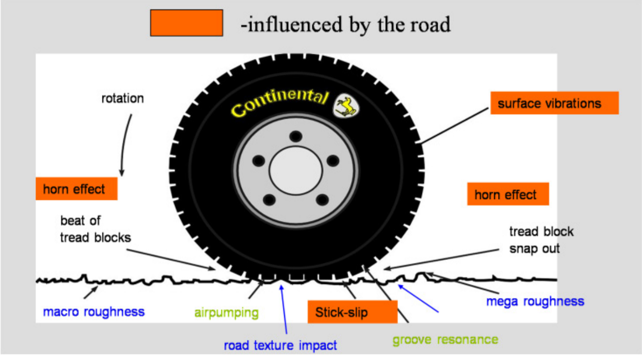

Figure 1: Noise mechanisms of tire/road interaction

It is known in the tire industry which part of a tire has an influence on which acoustic property. Some of the dependencies are displayed in figure 2. To lower exterior noise coming from the tread band (pattern) the tread block dynamics and the footprint shape must be changed. This can be realized by changing the tread compound and/or the belt width. But changing the tread compound will also influence the transfer mobility and changing the belt width will change the natural frequencies and therefore the dynamic behavior of the tire.

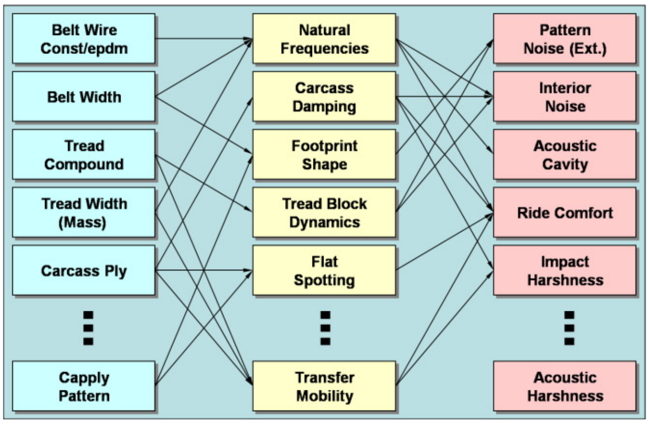

Figure 2: Interactions and influence on acoustic properties

As a general rule one can state that everything, which makes contact smoother over time and space will lead to a reduction of the medium and high frequency range contents of the contact forces.

2.2 Possibilities to build low noise tires

Kropp [1] proposed in a report of the SILENCE project the following possibilities for the control of noise due to tire vibrations:

- Changes of contact forces
- Changes of tire response: Increasing the mobility of the tire structure
- Changes of radiation properties

Experimental tires were build to investigate the potential of the different measures but due to strong interactions with other tires features must of the developments show no significant improvement regarding lowering the noise. Only the tires from the last loop with modified tire mobility were promising.

In the last loop the following experimental tires were built with a tread pattern of CPC2 in size 205/55R16:

• Serial tire	Serial reference tire CPC2
• Serial tire rebuild bead	Basis as reference without soft
• Tire 2	Basis + winter compound
• Tire 3	Basis + winter compound + heavy and soft belt
• Tire 4	Basis + winter compound + heavy and soft belt + soft bead
• Tire 5	Basis + winter compound + heavy and soft belt + soft bead + thick liner

It is assumed that the NVH performance will increase from serial tire rebuild to tire 5.

Micro-position	**VO**	**VO**	**VO**	**VO**	**VO**	
	Serial tire rebuild	Tire 2	Tire 3	Tire 4	Tire 5	Serial Tire
Leading edge 1m	91,1	89,5	85,2	84,8	84,4	91,6
Trailing edge 1m	90,5	89,0	85,8	85,5	85,0	90,3
Side 1m	87,0	85,1	82,2	81,4	80,9	86,0
Side 3m	80,3	78,0	75,5	75,0	74,2	79,9

Table 1: Overall Sound pressure level in dB (A) on safety walk at 80 km/h

In table 1 the overall sound pressure levels at 80 km/h measured on a dyno drum are listed. Compared with the serial tire all constructions are less noisy than the reference tire. Sound level difference at 3 m side up to -5.7 dB indicates that these constructions have a potential for low noise tires of the future.

After the promising results on the dyno the tires from table 1 were tested at the Continental proving ground in pass-by and coast-by tests. The measurements were done according to ECE R51.02 and ECE R117 on a certificated ISO 10844 track. The results displayed in figure 3 expected the measurement results for the serial tire and the rebuild serial tire at the same level but the sound pressure level in 3. gear during pass-by differs. Under this condition the rebuild tire radiates 1 dB higher level more which can be influenced by environmental conditions. Tire 2 is even 1 dB louder than the rebuild tire while all other tires are on the same level of the serial tire. In 2. gear also the tire 2 is louder than the serial tire while all other tires radiate are a little less. Bigger differences in the acoustic behavior where measured during coast-by at 60 km/h and 80 km/h. The serial tire and the rebuild serial tire are on the same level while all other tires are softened. Tires 3 to 5 are on the same low noise level. The results clearly indicate the problem to optimize a tire acoustically for free rolling and rolling under torque. All tires are built with the same tread pattern but different constructions.

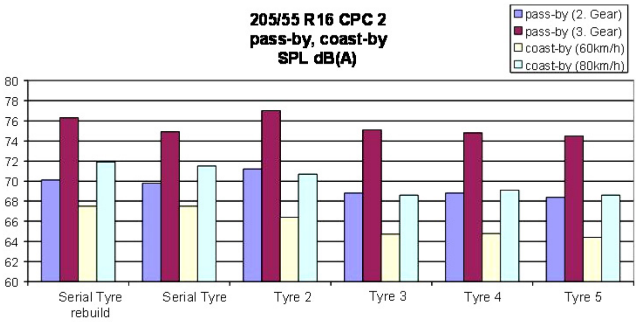

Figure 3: Exterior noise measurements of tires loop 4 at Continental in dB (A)

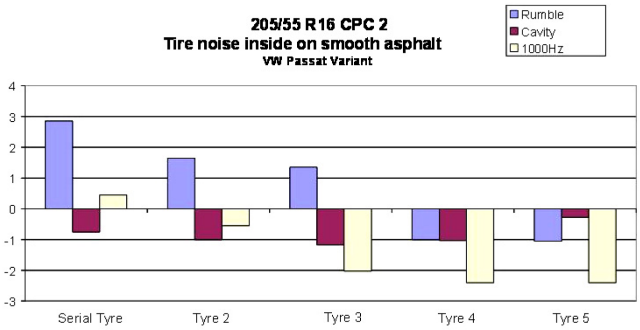

Figure 4: Comparison of interior noise measurements of tires loop 4 on smooth asphalt in dB (A)

An important development criterion for tires is the performance inside a vehicle. The overall level is depending on the acoustic isolation of the vehicle and therefore the results are presented only relatively to the rebuild serial tire. The measurements were made on a VW Passat Variant. In figure 4 the results for three frequency ranges are displayed. Rumble is caused by excitations in the frequency range 50 Hz – 200 Hz. Cavity is caused by the vibrating air column inside the tire in the frequency range 200 Hz – 280 Hz. 1000 Hz is caused by pattern vibrations and contents the frequency range 700 Hz – 1200 Hz (high frequency range). In contrast to the overall judgment from the exterior noise the detailed evaluation in the frequency range shows better the influence of the different measures.

2.3 Measurements of tires at BASt

The tires were also tested on eight low noise pavement surfaces in the tire road interaction test facility (PFF – figure 5) of BASt regarding tire noise emissions in near and far field. The tests were carried out at four different velocities at 100, 80 50 and 30 km/h. Both CPB measurements as well as CPX measurements were simulated. The result of the CPX measurements is the average of noise level of the microphones in CPX position (figure 6).

Figure 5: experimental set-up of indoor drum test facility and microphone position

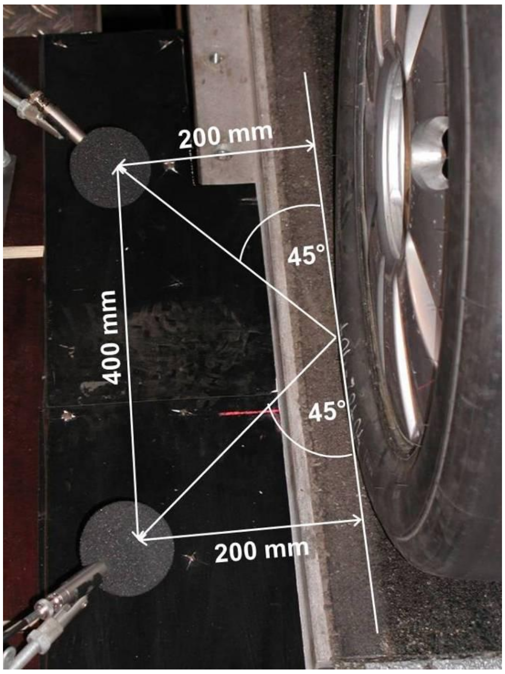

Figure 6: Near field microphone position (according CPX-position)

All six tires were tested on eight different surfaces that were mounted in the PFF's ring. Firstly the tests were carried out with the "Danish" surfaces SMA 0/4 and SMA 4+ /5/8. Nine caskets were filled with the "Danish" surfaces SMA 0/4 and nine caskets were filled with the "Danish" pavement SMA 4+ /5/8. Secondly the PFF's caskets were dismounted, turned around by 180 degrees in order to bring the rear pavement to the front. In the next step the six tires were tested on the "Danish" pavements SMA 0/6 and SMA 6+ /5/8.

After the completion of the tests with the "Danish" pavements the caskets have been dismounted again and the "Danish" pavements have been taken out of the caskets. In the next step the prepared "Swedish" pavements have been glued into the caskets. On the front side of the caskets the gap-graded reference and the open-graded reference pavements were brought to the front lane and the gap-graded rubber and the open-graded rubber to the back lane. In the following step the caskets have been mounted into the PFF's ring again. The gap-graded reference and the open-graded reference pavements were the first to be tested with the six different prototype tyres. When these tests were finished the caskets have been dismounted and turned 180 degrees in order to bring the rear pavements to the front.

The results of all tests either with Danish or with Swedish pavements have shown that the basic tires (Serial rebuild tire and serial tire) were the noisiest of all test-tires at all speeds. This result is valid except only the test on pavement SMA 0/6. During this test it turned out that the prototype tire with winter-compound (tire2) was noisier than the basic tire (serial tire rebuild) at all speeds.

Furthermore it pointed out that the two basic tires (Serial tire rebuild and serial tire) did not emit equal sound level but the serial tire was about 0.5 to 1.0 dB(A) more silent than tire rebuild serial tire at all tests.

3 Measurements in Copenhagen at Kastrupvej

3.1 Mix design of the pavements

In another work package of the EC project Silence investigations on new road surfaces has been made with the goal to optimize the mix design of asphalt material for thin surface layers with respect to their noise reducing capability [2].

The Danish part of the experiment focused on optimizing and developing thin noise reducing road surfaces. It was also decided by the project group to use the Stone Mastic Asphalt (SMA) concept as the background for all the pavements to be included in this part of the experiment.

The noise optimization is basically be done by:

- Using small maximum aggregate size (4, 6 and 8 mm) in order to achieve an even and smooth pavement surface that can reduce noise generated from vibrations in the tire
- Using a high built in air void in order to achieve a very open surface structure that can reduce noise generated from air pumping
- Using a small proportion of oversized aggregate in order to increase the openness of the surface structure
- Using as cubic an aggregate as possibly in order to achieve an even and smooth pavement surface that can reduce noise generated from vibrations in the tire.

In order to optimize the mix design Marshall samples have been produced in the laboratory of DRI and Colas Contractors and laboratory tests have been performed. From the test results the mixes to be tested have been selected on the strategy of trying to achieve a balance between long time structural durability and a good noise reduction. These mix compositions are laid out at Kastrupvej in Copenhagen and are tested under normal urban traffic.

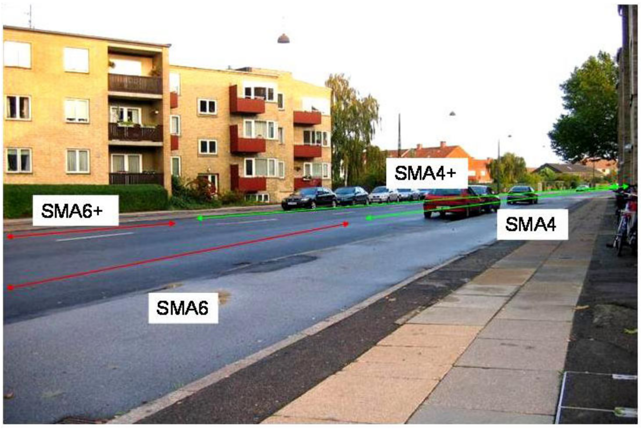

Figure 7: View of the measurement tracks at Kastrupvej -1

Figure 8: View of the measurement tracks at Kastrupvej -2

Figure 7 and figure 8 shows four of the new road surfaces. The fifth new surface with chipping size 0/8 mm is acoustically near the normal ISO 10844 grading curve and laid out away from the other four surfaces. The sound measurements under normal traffic were very time consuming, as only measurements with low background level could be used. Even these results are biased by the environment influences. Therefore the results from the far-field measurements are not discussed in the paper.

3.2 Near field measurements with on-board sound intensity method (OBSI)

From the research point of view the far field measurements with high background level on an urban road under real traffic are not satisfying. Therefore Continental has made also near field measurements which are less influenced by the background noise. In contrast to the normal trailer measurements commonly used by road builders sound intensity measurements were made. The measurement method was proposed by American Association of State Highway and Transportation Officials (AASHTO) in a draft standard *Measurement of Tire/Pavement Noise Using the On-Board Sound Intensity Method (OBSI).*

This test method describes the procedures for measuring tire/pavement noise using the on-board sound intensity (OBSI) method, and the procedures for verification of the measurement system. The test method provides an objective measure of the acoustic power per unit area at points near the tire/pavement interface.

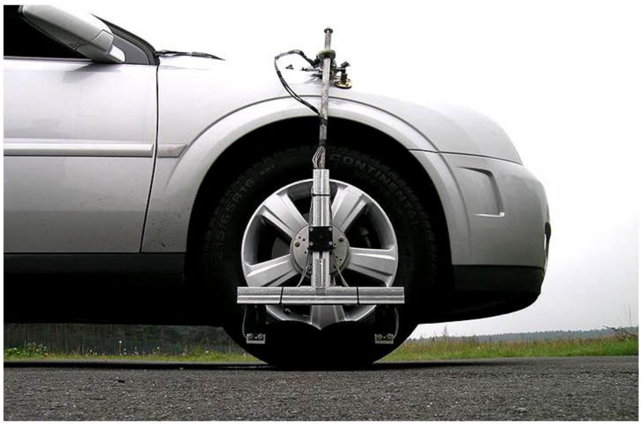

Figure 9: Side view of sound intensity probes mounted on a vehicle

The mounting of the fixture at the vehicle is displayed in figure 9. The results of the near field OBSI measurements displayed in figure 10 show clearly the improvement of the results. The levels of the serial tire and the rebuild serial tire are nearly on the same level as expected. The ranking is in principal the same as during the far field measurements. The influence of the soft compound could be measured but the big improvement occurs only in combination with the heavy and soft belt.

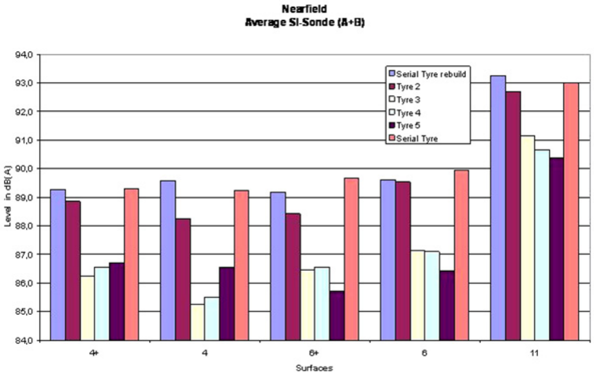

Figure 10: Comparison of the sound intensity measurements averaged at leading and trailing edge

All tires radiate more sound power at the trailing edge which is in line with our understanding that this is typical for smooth surfaces. In figure 11 the averaged sound intensity level over all measured surfaces are displayed. Tire 2 with the soft compound leads to an improvement by 0.5 dB and tire 3 to 5 are more than 2.5 dB less noisy on the new surfaces than on a SMA 11. In figure 12 the sound intensity on different surfaces is compared. All tested tires are in average more than 4 dB less noisy on surface 4 compared with a standard SMA 0/11.

From an acoustic point of view the development was quite successful but at the end it must be proved that the constructions have also normal useful tire properties.

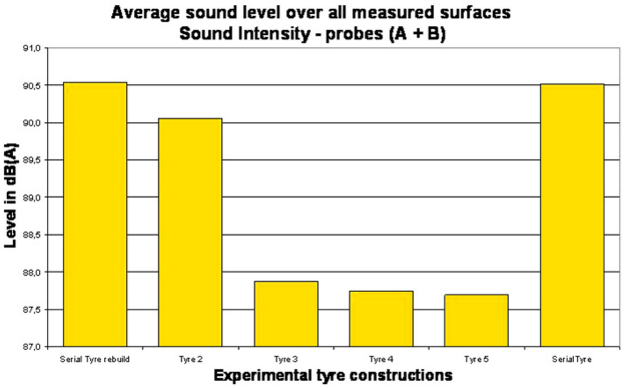

Figure 11: Averaged sound intensity level over all measured surfaces averaged at leading and trailing edge

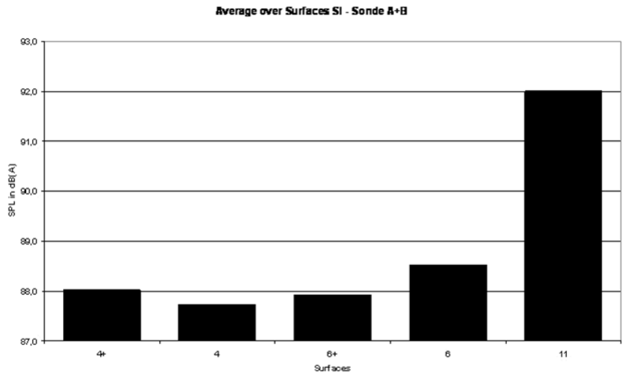

Figure 12: Comparison of the averaged sound intensity at leading and trailing edge on different surfaces

To check the basic tire performances tests on braking, aquaplaning, wear and rolling resistance were performed. In table 2 the tested other basic tire performance are compared relative to the rebuild serial tire. A value above 100 % means "better performance" and below 100 % means "worse performance".

Tire 2 with the winter compound shows a reduced performance in braking and aquaplaning but a big improvement in wear and rolling resistance. The further improvements which are good for less noise have no influence in braking and aquaplaning performance but influences wear and rolling resistance. All measures improve the rolling resistance. With the soft compound an increase of 10% RR is gained compared to the basic tire but when additionally a heavy and soft belt is added 7 % of RR is lost compared to the tire with the soft compound. Overall the rolling resistance of the new developments is improved by 3% compared vs. the basis. Regarding wear performance the additional heavy and soft belt gives a break-in. The performance decreases to 70 % compared to the basic tire construction with a weight increase of 1.6 kg.

Test criteria	Serial Tire rebuild	Tire 2	Tire 3	Tire 4	Tire 5	Serial Tire
ABS Braking						
Dry braking	100 %	95 %			95 %	
Wet braking low mu	100 %	68 %			68 %	
Wet braking high mu	100 %	89 %			89 %	
Aquaplaning						
longitudinal	100 %	91 %	94 %		93 %	
lateral	100 %	82 %	86 %		89 %	
Uneven wear						
Spec distance	100 %					
weight loss	100 %	130 %	70 %		70 %	
Rolling resistance		110 %	103 %	107 %	106 %	108 %
Weight	9.18 kg	9.39 kg	10.15 kg	9.77 kg	10.72 kg	9.18 kg

Table 2: Basic tire performances of the measured tires

4 Conclusion

Although a loose of 32 % of ABS wet braking on low mu surfaces is not acceptable for high quality tires, these tires of shows a clear way how to construct low noise tire in the future. With a different compound the disadvantage in wet braking can be compensated and as can be seen from the dates at the far right side of the table 2 it is possible to have a tire with:

Average wet braking and aquaplaning performance

- Lower rolling resistance
- Much lower noise level
- Perhaps higher purchase costs due to advanced materials

Acknowledgments

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References

[1] Kropp, 2006, WP C.1 Simulation and Evaluation. Guidelines for Noise Reduction, SILENCE deliverable

[2] Nielsen, Raaberg, Bendtsen, 2006, F2 Noise reducing SMA pavements – Mix design for Silence – F2, Silence deliverable