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Contribution of the tyre to further lowering tyre/road noise

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The tire is the only part of a vehicle that must be originally and primarily designed to transmit forces to outside the vehicle, and the amount of energy a tire consumes per kilometer in operation and for production has to be minimized. The tire manufactures are searching for many years for a construction, which fulfils the targets of the automotive industry and generates less noise. On dry, wet and snow-covered roads, the safety of traffic can only be ensured by sufficient capability for acceleration and braking deceleration, cornering stability, tracking on acceleration and braking, steering precision and direction stability. The high requirements on safety, economy and durability limit the possible reduction in the emission of tire/road noise.

1 Introduction

According to “future noise policy – European commission green paper” [1] 20% of the population in the EU is exposed to unacceptable traffic noise levels of more than 65dB(A) L_{Aeq} and another 45% are exposed to annoying levels of more than 55 dB(A) L_{Aeq} . Nowadays the essential mechanisms of noise excitation of a vehicle are no longer the motor and the power train but in the speed range 40 km/h to 120 km/h the tire/road noise. From 120 km/h on the wind noise is the main noise source. The I-INCE report [2] on Noise Emission of road vehicles-effect of regulations recommended “Noise emission from tires during normal driving must be substantially reduced. As long as this is not done, vehicle noise regulations are likely to be ineffective. Tire/road noise reductions may be achieved by use of a regulation similar to the amendment to the EU tire directive, but the limits must be substantially reduced to have any effect”. From a regulation standpoint this approach seems quite reasonable, but neither with regulations nor with measurements can tire/road noise be reduced. The approach for efficient societal benefit for rolling sound emissions has to be considered on a global basis where the main actors are the pavement, the vehicle and the tire. Traffic flow management and driver behaviour need to be included in this global approach. The tire industry is devoted to traffic noise reduction.

2 Tire Technology Basics

A tire is an important part of vehicle safety. The basic tire functions are:

- Carrying the load
- Transmission of forces from contact area to vehicle
- Damping of absorbing irregularities of the road

The small contact patch (footprint) is the only direct link between the vehicle and the road. This link must handle large forces under all conditions and this is possible only because the tire is a high tech product, engineered using the most modern tools.

The tire characteristics must ensure different requirements

- Safety (braking on dry, wet, snow and ice road as well as good aquaplaning behaviour)
- Handling (tire characteristics at high speed)

- Economy (mileage performance, fuel consumption (rolling resistance) and resources (weight))
- Environment (coast-by, emissions, fuel consumption (rolling resistance))
- NVH (mechanical and acoustical comfort)



Figure 1: Complexity of modern PC tires

A standard modern PC tire consists of ~10 tire parts and ~12 different compounds. As displayed in figure 1 a modern tire consists of tread(1), cap plies (2), steel-cord belt plies(3), textile cord ply (4), inner liner (5), side wall (6), bead apex (7), bead core (8) and bead reinforcement (9). Due to high interaction of the components a tire is a product with high complexity. From a physical standpoint of view a tyre is a fibre lacing rubber construction with nonlinear material behaviour under elastic, plastic and thermal deformation. To adjust the tire behavior to the requirements of the vehicle manufactures the tire engineer work on 4 areas as shown in figure 2.

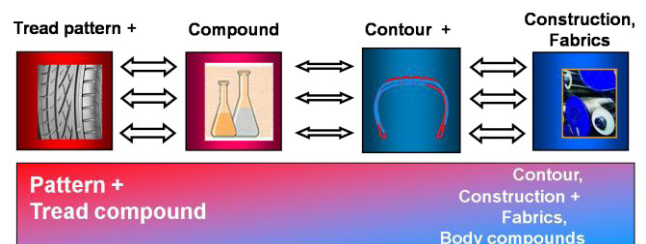


Figure 2: The four pillars of tire engineering

Principally the tyre engineer can change everything to reach to adjust the requirements but unfortunately there exists strong interactions between tread pattern and tread compound as well as between contour, construction, fabrics

and body compounds. Pattern and tread compound influences the features appearance, dry grip, wet grip, snow/ice grip and aquaplaning. The contour, construction & fabrics and body compounds influences the features high speed capability, durability and bead seating. All four areas have an influence on the features handling, coast-by noise, NVH, rolling resistance and wear behaviour.

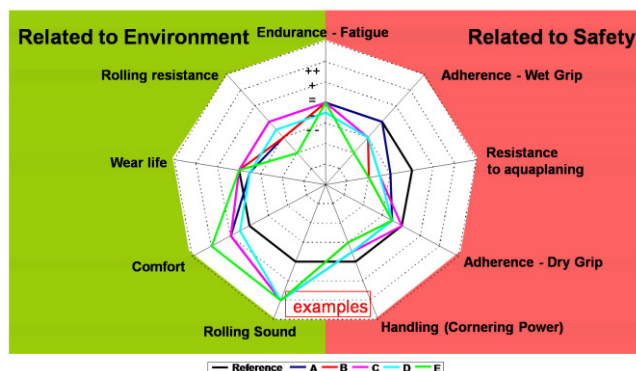


Figure 3: Performance compromise for tire constructions

A tire is no fridge which means that not only one feature is important. In figure 3 the most important features of a tire are grouped related to environment and to safety. In this spider diagram five examples of realisations are displayed. The reference is balanced in all features whereas examples A to E are optimized regarding noise which has an influence on the other tire features.

3 Target conflicts during tire development regarding rolling noise

The tire manufactures are searching for many years for a construction, which fulfils the targets of the automotive industry and generates less noise. One way to lower the rolling noise is to use a softer tread compound. In figure 4 the coast-by measurement results at 80 km/h of 3 tires on 3 road surfaces are displayed. The tread hardness is varied from a very soft winter compound to a normal summer compound used nowadays for sportive tires. By changing the tread hardness from 70 ShA to 50 ShA the sound level is decreased up to 3 dB(A). **A soft tread compound with low damping reduces the rolling noise by less excitation.**

Unfortunately tires with a tread compound of 50 ShA fulfill not the requirements of the automotive manufactures regarding handling and aquaplaning performance of a modern summer tire. Handling is an important safety criterion of modern tires. Vehicle driving dynamics, the subjectively and objectively measurable handling of vehicles in various stationary and transient driving manoeuvres is the crucial product characteristic for the differentiation of today's vehicles. The requirements towards the handling of modern passenger cars are constantly rising. Safe and easy driving are required characteristics. Car manufacturer typical requirements and also the driving fun for the final customer have to be considered.

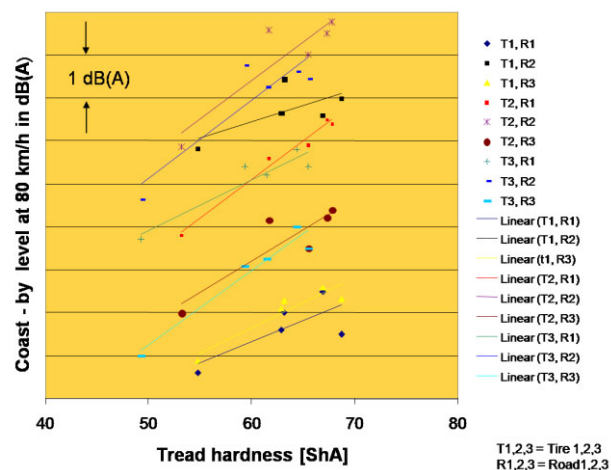


Figure 4: Influence of tread hardness variation on noise

The handling can be adjusted, depending upon selected chassis and drive concept, to same portions by the design of the chassis and by the tire as link between vehicle and roadway.

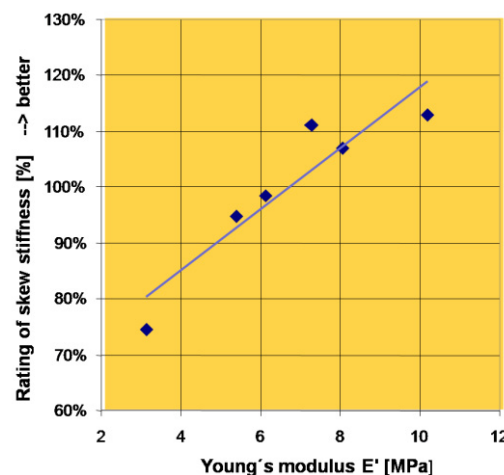


Figure 5: Target conflict driving dynamics

In order to optimize the linear handling the tire development concentrates on the level of cornering stiffness, the difference of the cornering stiffness between front and rear axle and the lateral stiffness of the tire. Higher cornering stiffness requires higher stiffness of the tire tread (figure 5) which results in higher excitation of the tire vibrations.

The other drawback of a soft tread compound with low damping is aquaplaning. Unfortunately for better aquaplaning behavior a tire should have high damping in the tread. But such compounds produce more excitation of vibrations in the tire which results in higher radiated sound levels.

At Continental a “rail track” is used for braking and straight line aquaplaning tests. For this the test vehicles are guided along a rail through a aquaplaning basin to reduce the influence of differences in the coefficient of friction from the road surface on the readings. The aquaplaning trial determines at what point in a previously specified water depth and at what speed the car can no longer channel water out of its ground contact patch and thus starts to 'float'. In

figure 6 the results from measurements at 15 % slip on straight line aquaplaning on a front-wheel drive are displayed vs. the measured sound levels during coast-by at 80 km/h. The aquaplaning results are scaled to a reference of 100. Values higher than 100 are better performance, less than 100 are worse performance. **With better straight line aquaplaning performance the sound level increases.**

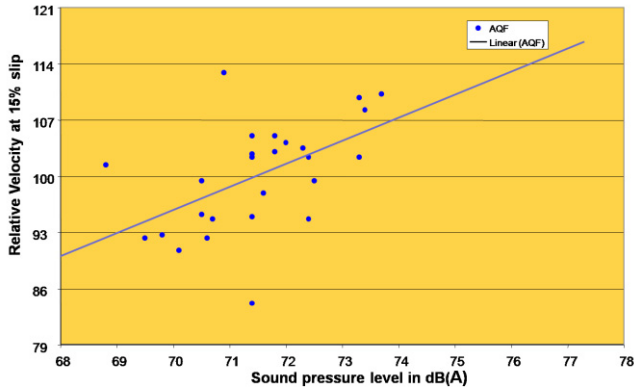


Figure 6: Influence on straight line aquaplaning front-wheel drive vs. sound level

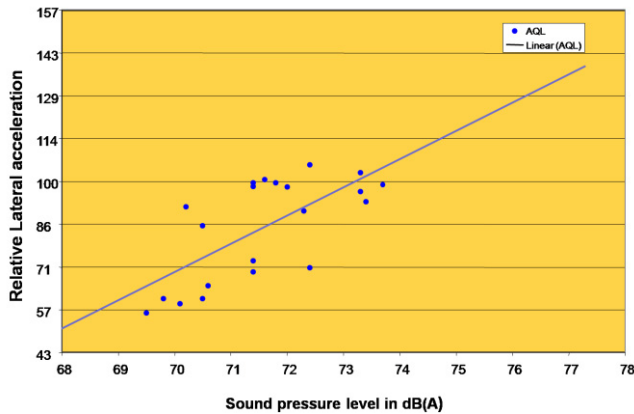


Figure 7: Influence of lateral aquaplaning vs. sound level

The lateral aquaplaning tests are performed on a circuit with a diameter of 200 metres to simulate primarily the situation of aquaplaning in bends. Speeds of up to 100 km/h can be driven on the large circuit. Both aquaplaning measurement situations are critical for all motorists in real traffic and they require particular attention in tire development. The results displayed in figure 7 are made on another test sample than displayed in figure 6 but show the same behavior for lateral aquaplaning. **With better lateral aquaplaning performance the sound level increases.**

Besides a tread compound with high damping the void volume of a tire is the main parameter to adjust the aquaplaning level required by the vehicle manufacturer. To show the influence on the sound level for the same tread profile the void longitudinal and lateral was varied. In figure 8 the results for the tread profile with a soft compound of 52 ShA is displayed. When the lateral void volume is decreased from 20 % to 10 % the coast-by sound level measured according UN ECE R117 is lowered by 7.7 dB!

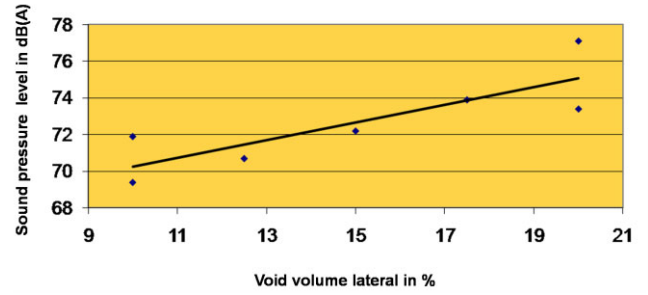


Figure 8: SPL at 80 km/h vs. void volume lateral for 52 ShA

The result depends of course also on the longitudinal void. With a void distribution 10% longitudinal and 10 % lateral a sound level of 69.4 dB(A) was measured while with a distribution of 20 % longitudinal and 10 % lateral a sound level of 71.9 dB(A) occurs. In principle it is better to have more longitudinal void volume than lateral.

With the same tread profile but a stiffer tread compound with 66 ShA the spread of the sound levels decreases to 4.3 dB(A) (figure 9). The problem for the development is that it is not sufficient to have only 10 % lateral void volume for a tire with good aquaplaning performance.

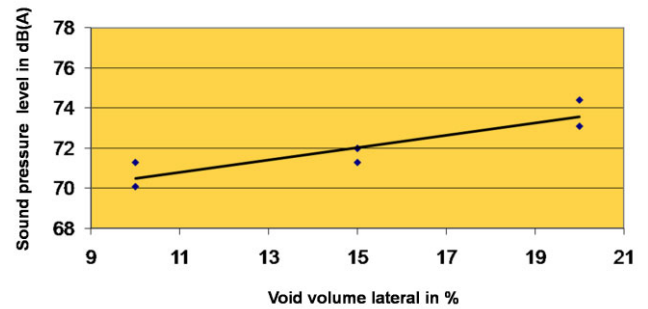


Figure 9: SPL at 80 km/h vs. void volume lateral for 66 ShA

For the wear performance of a tire it is helpful to design a tire with low void volume. In figure 10 the target conflict between wear, aquaplaning and noise is summarised. Europe modern tires have an overall void volume between 25 % and 32%. Perhaps with the coming climate change this range can be lowered.

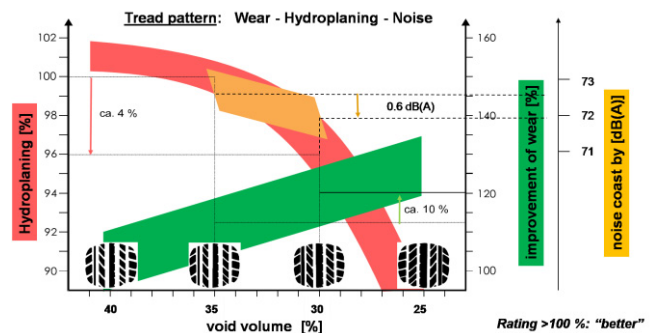


Figure 10: Target conflict wear-aquaplaning-noise

There is no real target conflict between coast-by noise level and wet braking on high μ surfaces but on low μ surfaces. The spread in the measurements made by Continental are quite large (figure 11) but there is a tendency that tires which are optimized for shorter wet braking distance on low μ surfaces radiates more sound during coast-by.

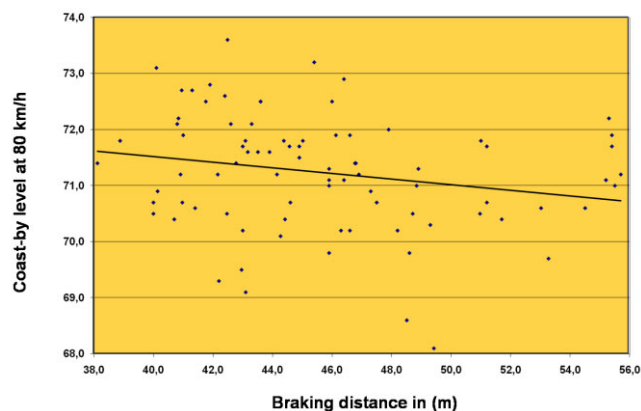


Figure 11: Wet braking on low μ surfaces vs. sound level

Another clear target conflict exists between optimizing a tire for low sound radiation and low rolling resistance although this is neglected in the literature by many authors from outside the tire industry. In figure 12 results published by TRL in 2008 are displayed which shows a correlation with $r=0,64$. The critical r value for $n=11$ and $p < 0.05$ is 0.62. Thus the correlation is significant with 95 % probability.

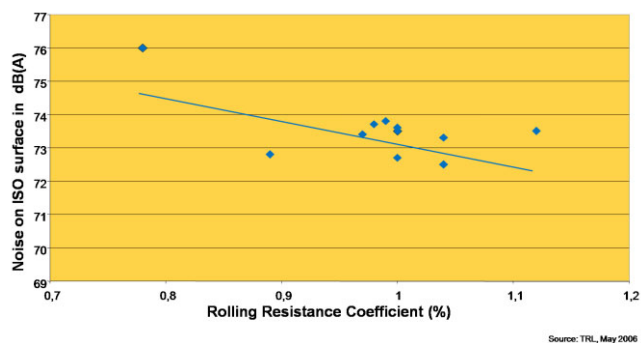


Figure 12: Rolling resistance vs. sound level

Reducing tire/road noise means today readjusting the performance. To study the influence on other tire performances for one specific tire construction modifications were made which radiates -3 dB sound level at 80 km/h.

- If the void volume is changed from 34 % to a slick tire:
 - Change in wet braking on low μ by -40 %
 - Change in aquaplaning lateral by -60 %
- If the tread compound is changed from a summer tread compound to ice tread compound:
 - Change in wear by -50 %
- If the tread mass is changed from normal tread to thicker under tread:

- Change in rolling resistance by $+15$ %
- Stiffness of modern tires is optimized for low noise radiation. An increase of stiffness so that the sound level is increased by $+3$ dB leads to
 - Change in wear by $+20$ %
 - Change in cornering stiffness by $+10$ %

4 Target conflicts during tire development regarding rolling noise

Tires must be developed regarding noise not only for free rolling but also for accelerated noise. Unfortunately measures to reduce tire/road noise under acceleration (pass-by) and under free rolling (coast-by) conditions are not always identical. In figure 13 the influence of damping on sound level increase under torque is displayed. The level **increases for lower damping** whereas under free rolling conditions the sound level decreases (figure 4) for lower damping. A tread compound with higher damping reduces the tire/road noise under acceleration by damping the tread block vibrations but leads to higher rolling resistance.

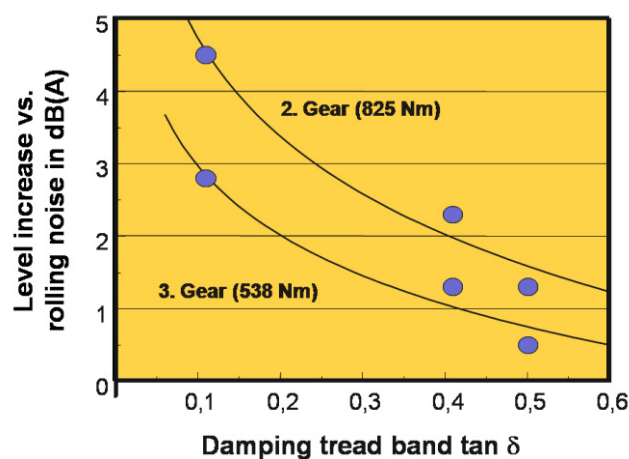


Figure 13: Influence of damping on level increase under torque at 55 km/h

Furthermore the ranking of noise sources in pass-by situations can be different from that in coast-by situations, in which tire/road noise doubtlessly is the main source.

5 Future Potential

The discussion of the target conflicts had shown that there are ways to lower the radiated sound of tires. If the main focus of the tire design is on low noise it is nowadays possible to build tires which are only 1 dB (A) louder than a blank tires. This can be reached mainly by tuning the tread pattern and by choosing proper compounds. A further reduction of tire excitation by tread pattern optimization cannot be expected. Because the tread pattern is needed to achieve the required safety level further noise reduction has to be addressed mainly by optimized tire construction. But this leads to the described target conflicts because the

requirements for noise, safety and rolling resistance on the tire construction are contradictory.

In developing tires in the future tire manufactures are obliged to follow the automotive mega trends:

- Environment
- Safety
- Affordable cars
- Information

The information trend has no direct influence on tire development. For affordable cars low cost tire technologies will be developed (with less mass and more radiated sound) and for safety the wet grip, dry grip and winter performance will be enhanced (see figure 6 and 7). Currently the most popular trend is on reducing CO₂ which press the tire manufactures to build tires with less rolling resistance. Using the new European driving circle (NEDC) the following distribution of fuel consumption of a passenger vehicle can be measured (table1).

	Total	Tire Share
RollingResistance	16%	16%
AirResistance	36%	4,5%
InternalFriction	32%	-
Inertial Resistance (Acceleration)	16%	0,4%
Total Resistance	100%	20,9%

Table 1: Distribution of fuel consumption

A 10% reduction in rolling resistance reduces the total fuel consumption by 1,6% which is equivalent to a CO₂ emission by 2g/km. As shown in figure 12 will a reduction in rolling resistance lead to higher coast-by levels and therefore the potential to lower rolling noise is limited in the future. To build tires with less rolling resistance is possible by a performance shift (figure 14) but at the same time the wet braking performance is lowered.

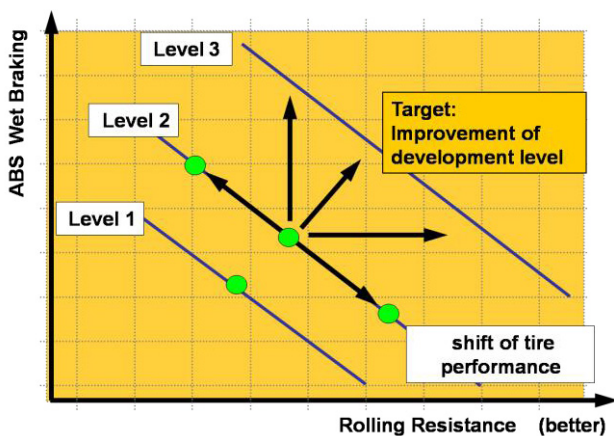


Figure 14: Improvement potential for rolling resistance and wet braking

Therefore the target for the tire industry is to improve the development level by less mass and new compounds with the drawback of increased rolling noise.

Another possibility for reducing the tire/road noise is a mitigation of trade-offs

- Focus shifting
 - Self supporting tires
- Shifting of tire tasks to other components
 - Absorbing wheel arches
 - Rim covers for trucks
 - Open porous asphalts

Tire/road noise in real life is generated on a wide range of road surfaces. The road surface has been proven to be an important contributor in the noise generation mechanism. Worldwide studies have estimated the potential of the road for tire/road noise reduction, e.g. up to 9dB (A) depending on the speed (VROM) and 14 dB (A) in the French “CPB” database. The absolute potential of the tire was evaluated at 4dB (A) by M+P whereas the measurements of the tire industry shows a potential of only 3 dB (A).

5 Conclusion

The tire is the only part of a vehicle that must be originally and primarily designed to transmit forces to outside the vehicle, and the amount of energy a tire consumes per kilometer in operation and for production has to be minimized. On dry, wet and snow-covered roads, the safety of traffic can only be ensured by sufficient capability for acceleration and braking deceleration, cornering stability, tracking on acceleration and braking, steering precision and direction stability. The high requirements on safety, economy and durability limit the possible reduction in the emission of tire/road noise.

References

[1] FUTURE NOISE POLICY, European Commission Green Paper, Brussels 1996

[2] Sandberg, Ulf :Noise Emissions of road vehicles – effect of regulations Final Report by the I-INCE Working Party on the effect of regulations on road vehicle noise, 2001 July in Noise/News International, pp.150-206, Vol. 9, No. 3, 2001 September