MEASUREMENT OF NOISE CHARACTERISTICS OF ROAD SURFACES

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ABSTRACT

This paper identifies tyre/road noise as a global environmental problem of greatest importance. It is a problem that is not yet under control; i.e., the noise exposure caused by tyre/road noise appears to increase with time. Since the road surface plays a major role in tyre/road noise generation, and also to some extent in its propagation, it has become important to establish standardized ways of quantifying the noise characteristics of road surfaces. Measurement methods for classification and other studies of road surfaces are explained in this paper. The two most important, the Statistical Pass-By (SPB) and the Close-Proximity (CPX) methods, are presented and commented briefly. A couple of examples of measurement equipment are given. The paper, furthermore, mentions the major measurement problems and suggests how the measurement results may be applied practically. Finally, some recommendations are presented.

KEY WORDS

PAVEMENT / NOISE / MEASUREMENT / METHOD / EQUIPMENT / ROAD SURFACE.

1. INTRODUCTION

Tyre/road noise has been identified at earlier PIARC congresses to be a major part of road traffic noise. However, the development of noise exposure over time has resulted in tyre/road noise becoming an ever more serious environmental problem. In Europe and Japan, it is now considered as the dominating contributor to road traffic noise exposure. With the dramatic traffic growth predicted for Europe in the next few decades, and the inability to solve the problem for others than the few most exposed people, the problem is not yet under control. This is the case for highly industrialized countries in Europe, North America, East Asia and Australia. Other countries may have slightly different traffic noise problems, albeit not less important, but other sources than tyre/road noise (like horns, two-wheelers and poorly maintained vehicles) may be an even greater nuisance in urban areas. Nevertheless, in many situations not even in such countries can tyre/road noise be neglected. It is thus a global problem.

Intuitively, many people would perhaps assume that most of the problem originates in the tyres. However, the noise generation is a result of a tyre/road interaction, with the road playing an equally important role as the tyre. Therefore, the characteristics of the road influence the noise emission at least as as much as the tyre characteristics. It follows that road design and condition are important features that the road authorities need to control also for noise emission reasons. Furthermore, selection of road surfaces has appeared as the (currently) most effective and quickly applicable way for noise control. Such selection must be based on objective data and thus it has become necessary to work out and use standard measurement methods for classification of road surfaces.

2. OBJECTIVES OF THIS PAPER

The objective of this paper is to provide a brief state-of-the-art review of current practices as well as future possibilities and needs with regard to the measurement of the influence of road surfaces on road traffic noise emission.

3. ROAD SURFACE PARAMETERS AFFECTING TYRE/ROAD NOISE GENERATION

Tyre/road noise is generated by a great number of mechanisms, many of which give substantial contributions to the overall noise but with various magnitudes under various circumstances. Since these mechanisms depend differently on certain road surface features, sometimes with opposing influences, the noise generation and its relations to surface properties are extremely complicated. The surface characteristics known or believed to influence traffic noise emission are listed in Table 1 together with an indication of the magnitude of the influence.

No.	Parameter	Degree of influence
1	Macrotexture	Very high
2	Megatexture	High
3	Microtexture	Low-moderate
4	Unevenness	Minor
5	Porosity	Very high
6	Thickness of layer	High, for porous surfaces
7	Adhesion (normal)	Low/moderate
8	Friction (tangent.)	See microtexture
9	Stiffness	Uncertain, moderate (?)

Table 1 - Parameters with a potential influence on tyre/road noise.

Macro-and megatexture have a dramatic influence on tyre noise emission. However, unlike the expectations of many people, noise emission does not increase uniformly with increasing texture. Texture dominated by wavelengths in the range 10-100 mm *increases* low-frequency noise, whereas texture dominated by wavelengths in the range 1-10 mm *decreases* high-frequency noise. Therefore, depending on the composition of the road surface texture, noise can be influenced in very complicated and not apparently consistent ways.

The porosity of the wearing course influences tyre noise emission by providing effective drainage of the air entrapped in cavities in the tyre/road interface and thus reducing the air displacement generation mechanisms, one of which popularly is called "air pumping". Furthermore, porosity may eliminate the amplification provided by the so-called horn effect; i.e., the amplification of sound generated at the leading and trailing edges of the tyre/road interface when propagating from the tyre to the exterior environment. Finally, but not the least: Tyre noise as well as power unit noise of the vehicle are partly absorbed by the sound absorbing properties of a porous surface when the sound propagates over the porous surface from the tyre to the exterior environment. The closer the source and the propagation path are to the porous road, the greater is the influence of the porosity.

Friction affects the tangential movements in the tyre/road interface. Adhesion (molecular attraction between two surfaces) affects the "stick-snap" that occurs when a tyre rubber block separates radially from the road surface asperity with which it is in contact. If adhesion is high, such separation will be delayed until the separation forces exceed a certain limit, and the tyre rubber will vibrate when released from the road surface. This mechanism has been neglected in the past but ongoing studies suggest that it may be quite important.

The stiffness of the road surface affects the mechanisms of impact (damping, etc) between the tyre tread and the surface texture. However, it is not known as to which extent stiffness actually influences noise emission in real traffic.

Despite three decades of research, the effects above (except texture and porosity) are not yet sufficiently explored with regard to their significance under various conditions. More information about the subject can be found in [Sandberg & Ejsmont, 2002] and [Descornet et al, 2000].

4. MEASUREMENT NEEDS

The needs to measure the road surface influence on noise can be summarized as follows:

- *Research:* current and emerging techniques to study different aspects of specific problems may be used
- *Type testing of surfaces:* a method is needed that has a high relevance to actual traffic conditions; this method may pose severe requirements with regard to the acoustical environment and the road location
- *Conformity of production (COP) testing:* a simple method that can be applied on all road sites is needed; feasible to apply in actual traffic although the circumstances may need to be chosen with some care
- *Testing of the influence of wear and age:* this can be made very much like COP testing
- *General surveys:* a simple and fast method is needed that can be applied on any road site with testing taking place by means of special equipment under normal traffic conditions; this must be useful on a nation-wide or regional-wide scale
- *Testing of special characteristics:* there is a need to test some special characteristics such as sound absorption of porous surfaces, as well as stiffness (mechanical impedance) and surface texture; these do not give a complete view about the performance, but may be useful to complement other methods

5. MEASURING METHODS IN USE AND STATUS OF STANDARDIZATION

5.1 Measuring methods overview

The following methods are used for studying the noise characteristics of road surfaces:

- The Statistical Pass-By (SPB) method
- The Close Proximity (CPX) method – using an extra enclosed test tyre (usually on a trailer)
- The Close Proximity (CPX) method – using a four-wheeled single-vehicle of which one of the ordinary tyres is replaced by a test tyre
- The Controlled Pass-By (CPB) method
- Sound absorption measurement in-situ

5.2 The Statistical Pass-By (SPB) method

An ISO standard for measurement of road surface influence on traffic noise (ISO 11819-1) was published in 1997. It is called the Statistical Pass-By (SPB) method and relies on a roadside measurement of the maximum A-weighted sound levels on a statistical selection of cars and heavy vehicles passing-by the microphone (a minimum of vehicles of each category). The measurements are processed in regression analysis of noise versus vehicle speed, from which an index called "Statistical Pass-By Index (SPBI)" is determined, which is the characteristic sound level for a standard mix of vehicles for the particular road surface at a chosen reference speed. This method satisfies the type testing need above and is currently widely used. A revision with the aim to improve certain details in the method is underway in the ISO group, starting in 2003.

A description of the method appears on the following page, including a rather typical measuring setup in Figure 1, which allows also frequency spectra to be recorded. A much more comprehensive description appears in chapters 14 and 16 of [Sandberg & Ejsmont, 2002].

The two main shortcomings of the SPB method are that it is a spot measurement (during the time of noise measurement each vehicle moves approximately 10 m) and that the road surroundings must meet stringent requirements regarding reflecting objects.

5.3 The Close-Proximity (CPX) method

To satisfy the needs of COP tests and general surveys, work is underway in ISO to standardise a measuring method for tyre/road noise called the Close-Proximity (CPX) method, which was previously called "the trailer method". "Close-proximity" refers to the principle of the method, which means that two microphones are positioned close to a test tyre that is rolling over the road test section (the microphones can be seen in the lower left picture in Figure 2). Four test (reference) tyres of different design are defined; see section 5.5. The test tyre is usually mounted in a trailer that is towed by a car or van, but the test tyre may also be one of the normal four tyres of a van or car.

A description of the method appears on the following page, including two examples of recently constructed devices (Figure 2). The first is one of the two very advanced devices used in Europe; the “Triton”. It is a truck equipped with a compartment covering a test wheel with microphones mounted nearby, all of which can be moved up and down. During test operation the test tyre and its compartment are pushed down in order to give the tyre a “normal” vertical load. The second one is the “Tiresonic Mk3” which is a more traditional trailer design with a test tyre inside an enclosure. A normal car tows the trailer. The enclosure can be moved up and down manually (easily done by one person) to provide access to the test tyre and microphones or for protection during measurements. There are several more devices such as these; refer to Chapter 16 of [Sandberg & Ejsmont, 2000].

An ISO committee draft, ISO/CD 11819-2, has been accepted and an ISO/DIS is underway in which the CPX method is utilised for measurements comparing the noise characteristics of road surfaces. An international experiment to test the CPX method and compare most of the trailers in-use today was conducted in the summer of 1998 in Europe. The CPX method is already widely used and the author is aware of new equipment currently being produced or planned in several countries. See further 5.5 about reference tyres.

The Statistical Pass-By (SPB) method

Minimum resources needed (see also Figure 1 below for this author's setup):

- Equipment for measuring speed of vehicles passing-by
- Sound level meter
- Tripod or other device to mount the sound level meter (or microphone) on
- Sound level calibrator
- Person reading speeds and taking notes about the type of vehicle passing-by
- Person reading the sound level meter

Procedure

The following is a summary of the procedure intended as an overview. In order to actually perform the measurement, it is necessary to study the entire standard.

1. Select a measuring site with plane and level road and no acoustically reflecting objects near the road. There should also be a wide paved shoulder or some other hard ground at the roadside
2. Mount the microphone 7.5 m from the centre of the road lane to be measured, 1.2 m above road plane
3. Calibrate the microphone
4. Measure speed and maximum A-weighted sound level of each vehicle passing by in the designated lane. However, the vehicle must not be disturbed by any other vehicle at the moment of maximum sound level. Each vehicle must also be categorized as either a car, a dual-axle heavy vehicle or a multiple-axle heavy vehicle.
5. Conduct measurements of this type until the measured number amounts to ≥80 cars and at least 80 heavy vehicles (including at least 30 dual- and 30 multiaxle vehicles).
6. For each vehicle category (the three mentioned above) plot in a regression diagram the sound level versus the speed, with speed scale being logarithmic.
7. Calculate the linear regression line for the measured points
8. Read the sound level of the regression line at a chosen ref. speed (for cars 50, 80 or 110 km/h, for heavy vehicles, 50, 70 or 85 km/h). This speed must be well within the speed range of the test road. The measure is termed L_{veh} (one per vehicle category).
9. For the chosen reference speed, weigh together (according to a special formula) the L_{veh} of the three vehicles categories in a manner resembling the proportion of these vehicles in a road situation of interest. A default mix of cars and heavy vehicles is defined but one may choose other mixes.
10. The resulting sound level is called the Statistical Pass-By Index (SPBI) which constitutes the final result.

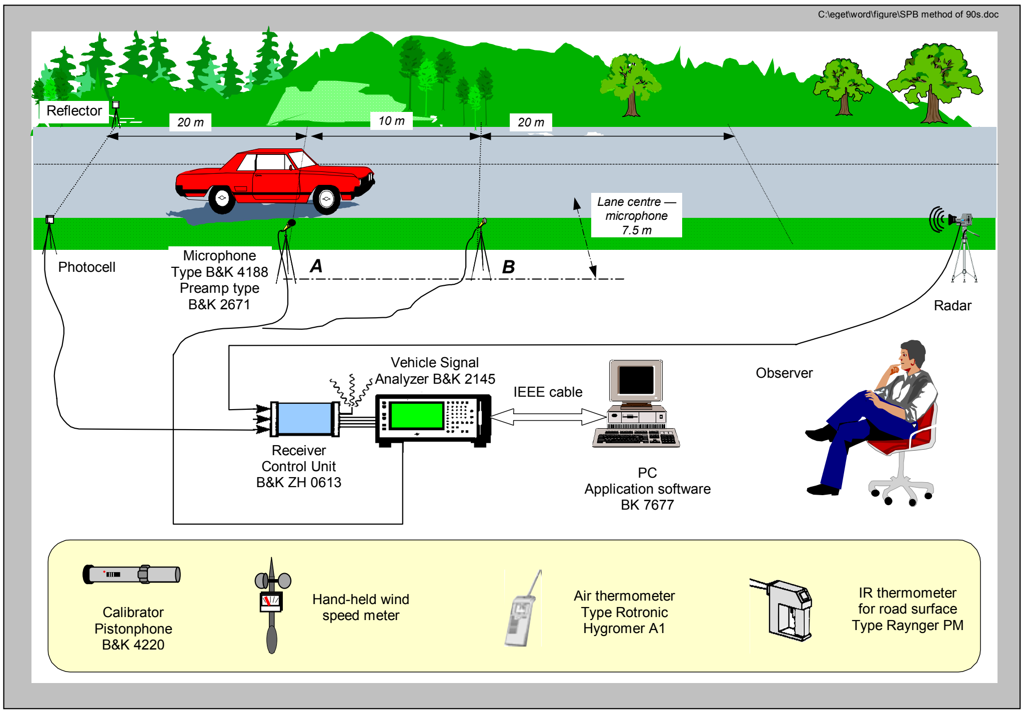

Figure 1 - The SPB measuring system used by VTI.

5.4 The Close-Proximity (CPX) method, using a four-wheeled single-vehicle

As indicated in 5.1, there is an alternative design principle for the test vehicle, which this author calls "four-wheeled single-vehicle". Instead of using a special trailer or a special test tyre inside an enclosure on a truck, such as the devices in Figure 2, some organizations have preferred to replace one of the normal four tyres on a conventional vehicle (car or van) with a reference test tyre. The standard allows such a construction too, but with special requirements. The reason for this simplified vehicle is, generally, that the cost of equipment may become substantially lower. However, this does not automatically mean that this type of measurement is less expensive or preferred, since it is far more exposed to imperfections in the acoustical surroundings. For example, special advanced precautions are necessary to protect noise from the other three tyres of the vehicle to reach the microphones, noise in the microphones from the fully exposed ambient airflow will be critical, as will be the occasional noise from other vehicles passing the test vehicle; in particular trucks. The latter type of disturbance will need manual postchecking of the measured signal in order to delete such events. Thus, the use of this alternative test vehicle needs highly qualified acoustical expertise in order to avoid results becoming erroneous or of low quality.

The above is emphasized because it seems that some organizations prefer this as a low-budget alternative and there is a risk that such reasons are accompanied by a lack of well-educated and experienced acoustical expertise having fundamental and deep knowledge about acoustics and acoustic measurements. This author thinks that the four-wheeled single-vehicle alternative may be used only if highly qualified and experienced acousticians conduct the tests. Thus, for organizations having limited resources, the low-budget alternative may seem attractive but might in fact be useless.

5.5 Reference tyres for the Close-Proximity method

The four test tyres used in the CPX method have been carefully selected due to certain features. Overall, the test tyres shall be stable in time (for limited wear) and available over a time period typical of the life of a measuring standard. More in particular, they have been chosen to represent the actual traffic on a typical road or street, as far as vehicle noise emission is concerned. Different tyres react in different ways to a range of road surfaces. The CPX method is for practical reasons developed for car tyres, but it is desirable that the influence of road surfaces on heavy vehicle traffic noise is also represented by the CPX method. It implies that one must find a car tyre that has properties similar to those of typical truck tyres, as far as sensitivity to road surfaces is concerned. The chosen four tyres (see Figure 3), are meant to represent the following noise-related sensitivities to road surfaces:

Tyre A: A tyre for use mainly in temperatures over 0 ^{o}C.
Tyre B: Same use as Tyre B, but a very different tread pattern
Tyre C: A tyre mainly intended for winter use (it can be equipped also with studs)
Tyre D: A tyre with a very old-fashioned winter tread pattern, having road-surface-sensitive characteristics similar to those of truck tyres

The suggested test (reference) tyres are shown in Figure 3. Note the large tread blocks of Tyre D.

The Close-Proximity (CPX) method

Minimum resources needed (see also Figure 2 below for typical test vehicles):

- Test tyres (four special reference tyres, defined in the standard)
- Trailer in which a test tyre can be mounted, having an enclosure to protect from disturbing noise and wind (alternative 1)
- Using a conventional car or van of which one of its rear tyres is used as a test tyre, and with special devices or material under the vehicle to reduce noise from the other tyres (alternative 2)
- Two microphones mounted at special locations outside the test tyre
- Sound level meter and sound level calibrator
- Person driving the test vehicle, reading speeds (from extra accurate speedometer) and sound levels

Procedure

The following is a summary of the procedure intended as an overview. In order to actually perform the measurement, it is necessary to study the entire standard.

1. Select a section of the road for measurement (no special requirements)
2. Make sure you have appropriate test equipment (see above and Figure 2) and mount one of the test tyres on it
3. Calibrate the microphone
4. Select your test speed, nominally 50, 80 or 110 km/h
5. Drive your test vehicle at constant speed over the selected test section (at least 20 m long but normally much longer, perhaps some km), in the appropriate wheel track, while measuring speed and the A-weighted sound level from each of the two microphones. Calculate the arithmetic means of sound level and speed over the test section. Note that if you use only a 4-wheel test vehicle (no trailer), certain procedures must be followed to remove thye influence of disturbing vehicles and disturbing wind noise.
6. Repeat the measurement at least one more time. Then calculate the averages for the number of test runs you made
7. Make measurements at another nominal speed (if desired)
8. Change to another test tyre and repeat all steps 4-7 above
9. Use the average sound levels for each test tyre to calculate a composite value including all tyres
10. The resulting sound level is called the Close-Proximity Index (CPXI), which constitutes the final result.




Figure 2 - Examples of recently constructed CPX measuring systems. The "Triton" used by TRL Limited in the U.K. (above, left) and the "Tiresonic Mk3" from the Technical University of Gdansk in Poland (above, right). The test tyres are seen inside the enclosures for the Triton (far left) and the Tiresonic Mk3 (left).

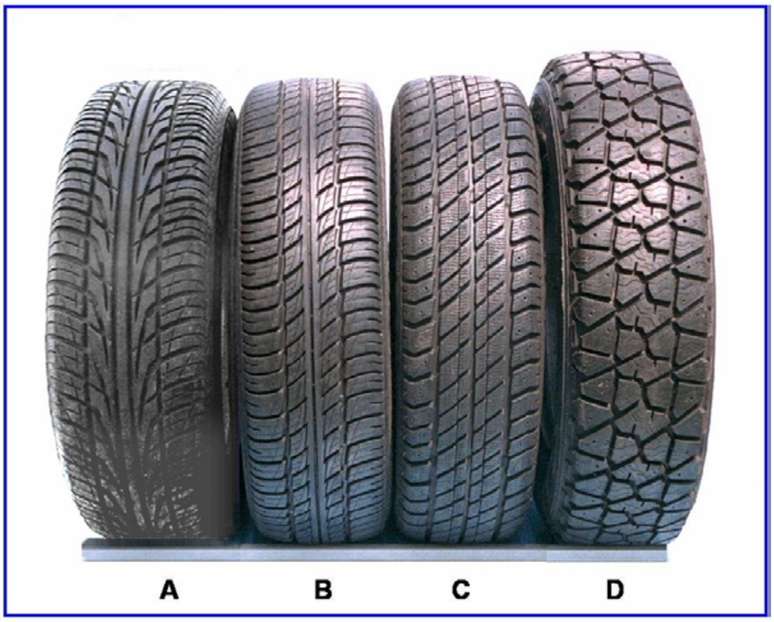

Figure 3 - The four proposed reference tyres for the CPX method.

At the time of writing this paper, there is a problem with availability of tyre D. This tyre is not available on the market since about 5 years ago. It had been proposed and planned that the tyre, however, would be kept available within a series of "vintage tyres". Related to a change of tyre company ownership, the mould for Tyre D disappeared and no more tyres of this type can be manufactured at the moment. It is not an easy task, if possible at all, to find a similar tyre that is available and having acceptable (car tyre) dimensions. Different solutions to the problem are currently considered, all of them relatively expensive. Tyre D is the most crucial tyre of the set since without it, the influence of heavy vehicle traffic on road surface noise characteristics cannot be assessed, unless one starts to use a special test truck that can accommodate a truck tyre.

There are several organizations in Europe that still have Tyre D in their test tyre stock.

5.6 The Controlled Pass-By (CPB) method

A method that was developed for testing tyres is also sometimes used for comparing road surfaces; namely ISO 13325. This specifies the so-called coast-by method for measuring tyre/road noise; i.e., a test vehicle is coasted past the microphone location with the engine switched-off. A variation of this is the so-called Controlled Pass-By (CPB) method, mostly practised in France, in which a few special test vehicles and test tyres are used as the measuring objects running at constant speed past the microphone on the road surfaces to be tested. A very large survey of noise characteristics of the French road network is based on this measurement method, which is specified in a national French standard.

5.7 Sound absorption measurement

Many "low-noise" road surfaces have significant sound absorption characteristics. ISO/TC 43/SC 1/WG 38 is responsible for carrying out standardization work aiming at measurement of absorption characteristics in-situ. One that is already worked-out (ISO 13472-1) is a free field method, measuring a surface of a few square metres, with special signals emitted by a loudspeaker above the road and with microphone(s) picking-up the signal for further advanced processing. Another method is being worked-out with the intention to arrive at an in-situ method with a better low-absorption resolution, utilising a tube method, which measures the absorption of a relatively small spot. These methods are mainly used for research and development so far.

5.8 Supplementary use of texture measurements

Some standardized methods for measuring road surface texture have been worked out. This includes ISO 13473-1 which specifies a method for measuring Mean Profile Depth (MPD) which has limited use for noise characterization, although it is widely used in road surface studies. More importantly for noise characterization, ISO 13473-2 includes a procedure for measuring the texture spectrum of a road texture profile curve.

Even though these methods are not yet possible to use for prediction of noise characteristics of road surfaces, and the MPD value will rarely be useful for this purpose, they may be useful to identify inhomogeneities of road surfaces that may influence a measurement of noise characteristics. For example, the SPB method is a measurement of the characteristics of the road surface on the particular spot (about 10 m long) that was selected as the measurement site. In order to make sure that a representative spot is chosen, one may make a texture measurement over a much longer test section and study the variation in texture with position along the road. Even a simple MPD measurement may be useful in this case.

5.9 Special topics of concern

Temperature has an influence on tyre/road noise measurements. An ISO group (ISO/TC 43/SC 1/WG 27) is currently studying this problem and aims to arrive at some general temperature correction formula or procedure. In general, noise decreases with increasing temperature. Since such influence is (very approximately) -0.1 dB per degree (celcius), a temperature effect of 2 dB is commonly encountered in road surface studies. It is thus necessary always to record air and/or road temperatures during a noise measurement.

The work to standardise the SPB and CPX methods has been and is being performed within ISO/TC 43/SC 1/WG 33 while the new EU project SILVIA will further study these methods and also provide detailed guidance on their use; see further below.

5.10 Reference surface

In many cases one would like to compare a certain road surface with some kind of common "standard" or "normal" surface. It may be termed "reference" surface since it is a surface to which a measured noise value for a particular "low-noise" or "high-noise" surface is referenced. Such a "reference" surface should preferably be included in any study that aims at determining the noise characteristics of road surfaces.

It should be pointed out here that a reference surface for noise testing has already been standardized; namely the one specified in ISO 10844. This surface is used widely in noise testing of vehicles and tyres; for example in ECE Regulation R51 and EU Directive 2001/43/EC (to name two of several). The problems in applying this reference to road surface testing are that (1) when using the SPB method, one must have normal road traffic on the surface and ISO 10844 is intended as a test track surface, and (2) the ISO 10844 is not yet specified so accurately that site-to-site variability can be neglected.

It is natural to pick out a surface type that is the most commonly used one as a reference surface. The problem is that surface popularity is a matter of time, country and even region. If one can define a range of surfaces having relatively similar noise characteristics, of which at least one surface would be common in a specific country and over a reasonable time period, the "average" of this range of surfaces could constitute a virtual reference. Work is underway in the EU project HARMONOISE (see the official website http://www.harmonoise.org/), having such a solution in mind. It may be useful for the reader to try to use a reference surface within the range considered in HARMONOISE, which is currently:

- all dense asphalt concrete surfaces with maximum chipping sizes 11-16 mm
- all stone mastic asphalt surfaces with maximum chipping sizes 11-16 mm

Later, it is possible that one may be able to correct from the actually used reference surface to the "virtual" reference surface and thus achieve a common worldwide reference. It is expected by this author that this solution gives an error that is no larger than the error (i.e. site-to-site variation) when using a "real" reference surface such as the ISO 10844.

6. COMPARISON OF METHODS

6.1 When to use the SPB or the CPX methods?

The Statistical Pass-By (SPB) method is designed to be as representative of real traffic conditions as possible. For this reason, it would always be preferable to use this method. However, it has a number of limitations. The most important one is its requirement of acoustical free-field conditions in the vicinity of the microphone. In practice, it means that there must be no significant, hard objects within a radius of 50 m from the microphone (except the road surface or ground itself). This immediately eliminates most of the road network from the use of the SPB method. For example, some types of safety barriers may be unacceptable. It must also be possible to find a place having, or temporarily add, a hard surface between the studied road lane and most of the way to the microphone position.

Another limitation of the SPB method is the requirement to measure at least 80 heavy vehicles of which at least 30 shall be dual-axle and 30 multi-axle heavy vehicles; for statistical reasons. That many vehicles must pass the microphone without being disturbed by other vehicles and with an approved measurement as a result. On certain road sites it takes a very long time until so many heavy vehicles have passed under suitable conditions. On some other road sites, the contrary problem may exist; there are too many vehicles passing. If traffic intensity is too high, it will be too rarely that a vehicle passes-by without any disturbance from another vehicle.

Therefore, the SPB method is useful mainly for testing a surface type at a test site that may be chosen by the testing organization to comply with the ISO 11819-1 site requirements. An obvious application is type testing of a certain surface. However, provided one can find suitable test sites, it can be used for also other noise classification purposes.

The Close-Proximity (CPX) method has the same main objectives as the SPB method, but is intended to be used specifically in applications that are complimentary to it, such as the following:

- Noise characterisation of road surfaces at almost any arbitrary site, with the main purpose of checking compliance with a surface specification (COP testing).
- Checking of the state of maintenance. It may involve wear of and damage to surfaces, as well as clogging and the effect of cleaning of porous surfaces.
- Checking of the longitudinal, and possibly also lateral, homogeneity of a road section.

The CPX method is essentially insensitive to the acoustic surroundings of the road, is faster, more practical and more economical than the SPB method. However, since it measures only tyre/road noise, it is more limited in the sense that it is relevant only in cases where tyre/road noise dominates and power unit noise may be neglected.

For survey purposes; i.e., noise mapping of a large road network, the CPX method is superior to the SPB method.

Although the SPB method is suitable for type testing, it must be observed that it is only a spot measurement. In order to make sure that the chosen spot is representative of a larger part of the road, one may supplement the SPB measurement with a CPX measurement that continuously measures the noise characteristics of the surface over a long distance; albeit with a limited representativity. Therefore, as part of a general noise classification system for road surfaces, the SPB and CPX methods are supplementary.

6.2 Correlations between the SPB and CPX methods

An international experiment to test the CPX method and compare most of the trailers in-use today was conducted in the "summer" of 1998 in Europe. It also included tests on the same surfaces with the SPB method. This is the major source for comparison of the methods currently available [Steven at al, 2000]. The experiments showed that the trailers differed substantially in their measured results, although this could essentially be traced to imperfections in the trailer designs that should not have occurred if they had observed all requirements of the draft standard. The experiments further showed a good relation between the values measured with the two methods (CPX versus SPB).

Examples of recorded correlations between the SPB and CPX methods are shown in Figures 4-5. These measurements were made using the TUG Tiresonic Mk2 trailer. The results are shown first when considering only cars and car tyres (Figure 4) and then when considering only multi-axle heavy trucks and the truck-simulating tyre D (Figure 5). The figures show that the methods have a good correlation with each other. They also show that the noise levels recorded with the CPX method generally are about 20 dB higher than those of the SPB method (16 dB for heavy vehicles). The main reason for this is the much closer measuring distance in the CPX method (approx. 0.3 m between microphones and source instead of 7.5 m).

7. ONGOING RESEARCH AND SOME RESEARCH NEEDS

In 2002, a European project with the acronym SILVIA started (see www.trl.co.uk/silvia). It aims at providing guidelines for all those working with road surfaces and their influence on noise, encompassing measuring methods as well as performance of various surface types. Although the focus is on noise properties, also other properties will be considered, in order to make sure that surface selection does not neglect aspects of safety, economy and other environmental topics. One of the aims is to develop a type and COP testing system for road surfaces.

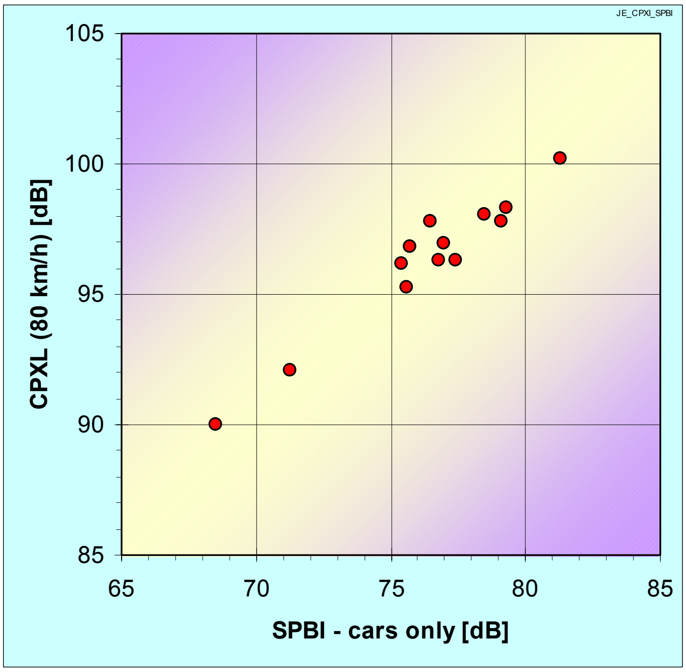

Figure 4 - The CPX index for light vehicles (CPXL) plotted versus the SPB index for cars, as obtained in the CPX Validation Experiment [Steven et al, 2000], for the TUG trailer. Reference speed is 80 km/h. Each data point represents one tested road surface.

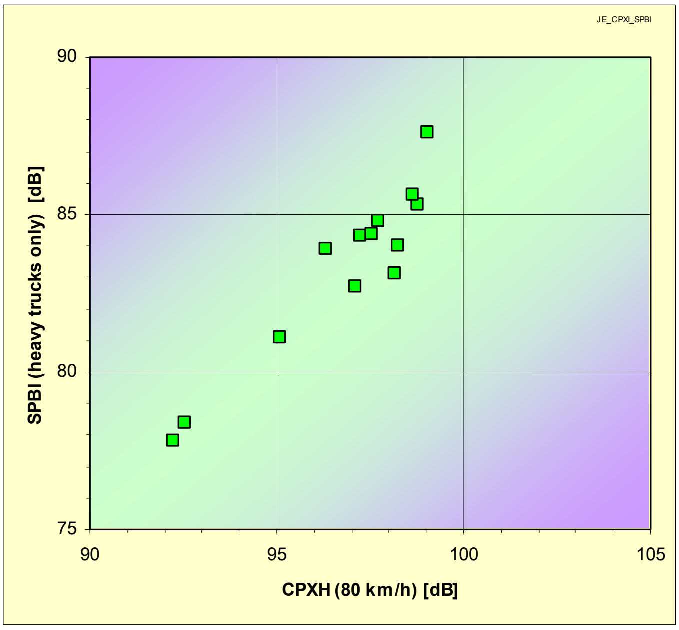

Figure 5 - The SPB index for 100 % heavy vehicles plotted versus the CPX index for heavy vehicles (CPXH, derived from tyre D), as obtained in the CPX Validation Experiment, for the TUG trailer. Reference speed is 80 km/h. Each data point represents one tested road surface.

The Dutch government has launched an extremely ambitious R & D program called IPG [IPG, 2002]. In English this translates to "Innovative Noise Reduction Program for Road Traffic". This program has its momentum on producing "Silent roads", but measuring methods will also be treated comprehensively.

More research and testing is needed to improve the equipment used for the CPX method, and especially how to test the performance of it. It is also desirable to explore further the relationship between the CPX and SPB methods and how to improve the reproducibility of both of them. The influence of road surface stiffness and a method to measure it are also needed. These topics are currently being addressed in the SILVIA project.

It would also be desirable to work out methods that would allow better laboratory testing of road surface noise characteristics, at least for R & D purposes. Today, laboratory testing of road surfaces can be made only on drum machines that allow mounting of road segments around the circumference of the drum. For safety reasons (centrifugal forces), this may be achieved only for laboratory facilities where tests are made on the inside of a drum or where the drum is at standstill and the test tires move. Such facilities currently exist only at BASt in Germany and SQDH (Purdue University) in Indiana, USA, as far as this author is aware.

It is expected that the European Commission will publish at the end of 2003 a call for a "Quiet Transport" integrated project. Such an integrated project may typically have a total budget of 20-50 million Euros over a time period of about 4 years. It is very likely that this project, when realized, will have significant tasks dealing with the subject of this paper.

PIARC has a certain tradition of organizing international experiments and it has been considered whether one related to noise would be justified. However, bearing in mind the mentioned SILVIA project and the huge Dutch IPG program, PIARC could do little extra to improve the knowledge about the various measuring methods within a foreseeable future. But an important role of PIARC the coming years would primarily be to synthesize and summarize for the road sector the knowledge about road surfaces and traffic noise emission.

8. POSSIBILITIES OF REGULATIONS BASED ON THE METHODS

Type testing of road surfaces using the SPB method could constitute a basis for a regulation system, within which surfaces must meet certain noise criteria in order to be approved for certain applications. The recent acceptance of ISO 11819-1 as a CEN standard is an important step towards a European framework for common requirements on road surfaces in this respect. Such a system should not only consider surfaces in new condition and at the location chosen for the SPB measurements but also meet the criteria at other conditions and locations. To this end, the CPX method may be employed. Once these methods are accepted, a regulation system including noise requirements is possible.

Some countries, like the Netherlands and the U.K. are already considering this. In fact, in the U.K., a type testing system for some types of proprietary surfaces, based on the SPB method, is already in use [HAPAS, 2002]. The 6-stage procedure to evaluate a new road surface material is outlined in Table 2.

In the Netherlands, a system of economic compensation for laying low noise road surfaces is already in use; see 22.9.1 in [Sandberg & Ejsmont, 2002].

Finally, the use of detailed road surface correction factors in the traffic noise prediction methods may provide a system that encourages the use of low noise road surfaces, since the calculated noise levels will more easily meet noise immission limits in the road environment. Such correction factors can only be determined if using the measuring methods described in this paper. This is actually the case in ongoing work in HARMONOISE; which is a European project with the aim of producing a common traffic noise prediction method for the whole of Europe.

Table 2 - The U.K. Highways Agency 6-stage procedure for evaluating new materials

Stage number	Action
1 Assessment of Applicant's data	Assess and evaluate existing information on the material
2 Assessment of production control	Assessment of quality control procedures of the Applicant or Installer, e.g. ISO 9000 certificate
3 Laboratory Testing	Test the mechanical properties to allow theoretical predictions to be made of their performance
4 System Installation Trial	Evaluation of construction and performance of materials over two years on at least five road sites
5 System Performance Trial	Provided the previous stage was not successful, a full-scale trial over two years may be made, including visual observation and texture depth measurement (some optional tests may be required too, like noise)
6 Certification	A certificate will be issued in the BBA Roads and Bridges series that verifies the system's compliance with the requirements. The validity of the Certificate is reviewed by BBA every five years. At least two annual visits by BBA to each production location and/or Certificate Holder's office shall be made

9. SPB - A SIMPLE METHOD FOR MEASURING NOISE CHARACTERISTICS OF ROAD SURFACES

In principle, the SPB method can be performed without having access to advanced measuring equipment; see above. However, the personnel performing the measurements must have basic knowledge about acoustics and be able to judge the acoustic separation between potential test vehicles passing-by the microphone. One must be aware that the SPB method relies on the stability in average noise produced by the vehicle stream in one place versus another one, in order to make possible a comparison of road surfaces. One cannot then accept that vehicles of a given type on one road emit a significantly different sound than the same type of vehicles on the other road(s) since this cannot then be distinguished from the real road surface influence. This could be a problem in developing countries where vehicles in different locations might differ largely in their condition and initial performance. It is also important to observe that the SPB Index is not only related to the road surface characteristics but is also affected by the noise emission from the power units of the vehicles; the latter of which are sometimes in actual traffic far from their new and quiet condition due to poor maintenance.

10. RECOMMENDATIONS

It is recommended that PIARC continues its review of the international development in this subject area with the purpose to disseminate and spread knowledge to the road engineering community worldwide. Its committees can also provide recommendations and advice to the organizations conducting research on this subject and support them by emphasizing the importance of the matter for sponsoring authorities. Liaison with the mentioned large projects (SILVIA, IPG and an expected new EU project) is then desirable. Since there are extensive R & D activities initiated and running for the next 3-10 years, PIARC will face the challenge of disseminating and spreading the knowledge resulting from these projects in the next two 4-year terms of PIARC.

It is thus recommended that PIARC C1 works with this subject *with a higher ambition during the next few years than currently.*

11. REFERENCES

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