M+P Raadgevende ingenieurs bv
member of Müller-BBM group
Bruistensingel 232
NL-5232 AD 's-Hertogenbosch
The Netherlands
tel. +31-(0)73-6408851
fax +31-(0)73-6408852
url: http://www.mp.nl

NOISE AND VIBRATION CONTROL

To	ISO TC 43 WG 42	From	G.J. van Blokland / E. de Graaff
Att.		E-mail	blokland@db.mp.nl
Your reference		Our reference	MVM.00.4
		Date	December 1, 2003

REMARK:

- the following text consists of three parts:

  1. a general quick introduction to the terminology of the GUM (chapters. 1-4)

  2. a description of the sources of error of the revised 362 procedure (chapter 5), proposed to form the annex on uncertainty

  3. a proposal for a text of the uncertainty paragraph in main body (chapter 6).

- **IMPORTANT:** The present text refers mainly to passenger cars, several of the items will also be relevant for heavy vehicles and for motorcycles, however additional work must be done to fill in the data for these vehicle types, for instance the effect of temperature on rolling noise of truck tyres is considered to be much smaller then for passenger car tyres. Also there is a much smaller effect of speed inaccuracies since no acceleration data is calculated from it.

Subject **uncertainty paragraph in standard of external vehicle noise revision 2**

1 Introduction

ISO standards describing methods and procedures for estimating the value(s) of a certain quantity must comprise a paragraph on uncertainty in the measurement result.

This memorandum has the following intentions:

1. to give insight in the nature of uncertainty

2. to explain the terminology used when describing uncertainty according to ISO directives

3. to define and estimate sources of uncertainty in the revised ISO 362 procedure

4. to come up with a text proposal for the uncertainty paragraph.

Uncertainty in general means doubt about the validity of the result of the measurement. Since knowledge about the uncertainty of a measurement is nearly as important as knowledge of the result itself, ISO has dedicated a special directive to it; 'Guide to the expression of uncertainty in measurement" which is also referred to as GUM. This memo is based into a large extent on this guide. I used the first edition of 1995 with ISBN 92-67-101889.

This guide addresses the issue of uncertainty very thoroughly and I tried to filter out what is important for the discussions in WG 42.

2 Uncertainty

2.1 definitions

The objective of a **measurement**[1] is to determine the **value** of the **measurand**, that is the particular quantity to be measured. An ISO standard therefore comprises a specification of the measurand, the **method of measurement** and the **measurement procedure.** However the **result of the measurement** is only an **estimate** of the value of the measurand and thus is completely only when it is accompanied by a statement about the **uncertainty** of that estimate.

In practice the required specification or definition of the measurand is dictated by the required **accuracy of the measurement**.

In general a measurement has imperfections which give rise to an error in the result. Two type of error components are distinguished, namely random error components and systematic error components.

- Random errors are caused by unpredictable and stochastic variations in quantities that influence the measurement result. Although one cannot

[1] the bold quantities refer to definitions that are defined in the GUM

compensate for them, the error can be reduced by increasing the number of observations. Characteristic is that the expected value (or expectation value) of a random error is equal to zero.

- Systematic errors are caused by influencing factors that "push" a measurement result in a certain direction and therefore the expectation value if this error is not equal to zero. If this factor is known, then it can be compensated for by applying a correction or a correction factor and after that, it can be assumed that the expectation value is zero again.The GUM is unclear with respect to systematic errors for which no correction exists, such as influence of air pressure, humidity and temperature on propulsion noise and environmental factors on sound propagation. Possibly these factors are to become a part of the definition of the measurand.

2.2 Sources of error

Errors on the result cause an uncertainty, which reflects the lack of exact knowledge of the value of the measurand. In practice there are many sources of uncertainty:

- Incomplete definition of the measurand
- Imperfect realization of the definition of the measurand
- Non-representative sampling, i.e. the sample measured does not represent the defined measurand
- Inadequate knowledge of the effects of environmental conditions and imperfect measurement of environmental conditions
- Personal bias in reading analogue instruments
- Finite instrument resolution
- Inexact values of measurement standards and reference materials , of constants and parameters obtained from external sources and used in data reduction algorithms;
- Approximations and assumptions incorporated in the measurement procedure;

2.3 Uncertainty definitions

2.3.1 Standard uncertainty

This is the uncertainty in the result of a measurement, expressed as a standard deviation (68% of all measurement results lie within + or – the standard uncertainty). ISO distinguishes evaluation in type A and type B.

Type A method is based on statistical analysis of series of measurement, type B is based on other than statistical analysis.

2.3.2 Expanded uncertainty

This quantity defines an interval about the result of the measurement that encompasses a large fraction of the distribution of values that could reasonably be attributed to the measurand. This fraction may be viewed as the coverage probability or the confidence of the interval.

2.3.3 Coverage factor

The multiplier used to obtain the expanded uncertainty from the standard uncertainty. This factor is typically in the range of 2 to 3.

3 Evaluating standard uncertainty

3.1 Type A evaluation

In most cases, the best estimate of the expected value μ_q of a quantity q that varies randomly and of which n independent observations q_k have been obtained under the same condition of measurement is the arithmetic mean or the average of the n observations:

$$\bar{q} = \frac{1}{n}\sum_{k=1}^{n} q_k$$

The variance can be estimated on base of the differences between the individual values and the average:

$$s^2(q_k) = \frac{1}{n-1}\sum_{k=1}^{n}(q_k - \bar{q})^2$$

The best estimate of the variance of the mean is given by:

$$s^2(\bar{q}) = \frac{s^2(q_k)}{n}$$

The square root $s(\bar{q})$ quantifies how well $\bar{q}$ estimates the expectation of μ_q of the quantity q this quantity can be used as the type A standard uncertainty.

This analysis assumes that the random observations are not correlated. Special statistics must be applied in case of correlation.

3.2 Type B evaluation

In case there is no set of repeated observations available, the standard uncertainty must be evaluated from scientific judgement based on all of the available information on the possible variability in the result of the measurement of a measurand. The pool of information may include:

- Previous measurement data
- Experience with or general knowledge of the behaviour and properties of relevant materials and instruments
- Manufacturers specifications
- Data provided in calibration and other certificates
- Uncertainties assigned to reference data taken from handbooks.

3.3 Determining combined standard uncertainties

In case of a measurand Y which is a function of measurands X_i

$$y = f(x_1, x_2, ..., x_N) \quad (1)$$

the estimate y of the measurand Y can be obtained from estimating the measurand of each X_i and then applying the given function.

(in some cases the estimate y may be obtained from:

$$y = \overline{Y} = \frac{1}{n}\sum_{k=1}^{n} Y_k = \frac{1}{n}\sum_{k=1}^{n} f\left(X_{1,k}, X_{2,k}, X_{3,k}, ..., X_{N,k}\right) \quad (2)$$

The standard uncertainty in Y must be calculated on base of the standard uncertainties in X_i as follows:

$$\mu_c^2(y) = \sum_{k=1}^{n}\left(\frac{\partial f}{\partial x_k}\right)^2 u^2(x_k) \quad (3)$$

This formula assumes that the measurands X_i are not correlated, otherwise the mathematics get quite complicated.

4 Determining expanded uncertainty

Although the standard uncertainty is an universal expression of the uncertainty in a measurement, in several application it is often necessary that uncertainty is expressed in such a way that the interval defined by it encompasses a large fraction of all possible results of the measurand, or that the a statement is given on the chance that the "true value" lies within the defined interval.

The uncertainty measure meeting these requirements is the *expanded uncertainty* and will be denoted by U. The expanded uncertainty is obtained by multiplying the standard uncertainty by a *coverage factor k*:

$$U = ku_c(y) \tag{4}$$

The result of the measurement is then conveniently expressed as:

$$Y = y \pm U \tag{5}$$

The coverage factor can be chosen such that the result U can be interpreted as the width of a certain confidence interval (although the GUM states that this is statistically not totally true).

From the Student t-distribution it can be found that with 6 measurements (5 degrees of freedom) , *k=2,0* represents a confidence of 90%. With infinite degrees of freedom k=2 equals 95%, however the strongest effect is of course the reduction of the standard error by the square root of n.

5 Aspects of uncertainty with revised 362 procedure (proposal for annex).

5.1 Sources of systematic and random error

The revised 362 procedure is subject to both systematic and random errors.

Random errors are due to:

1. inaccuracies in measurement devices such as sound level meters calibrators and speed measuring devices;
2. Variations in local environmental conditions that affect sound propagation at the time of measurement of L_{Amax};
3. Variations in vehicle speed and in vehicle position during the pass-by run;
4. Variations in local environmental conditions that affects the characteristics of the source (after compensation by already known systematic effects)

Systematic errors are due to:

1. Effect of environmental conditions that influence the mechanical characteristics of the source, mainly engine performance (air pressure, air density, humidity, air temperature)
2. effect of environmental conditions that influence sound production of the propulsion system (air pressure, air density, humidity, air temperature) and the roiling noise (tyre and road surface temperature, humid surfaces)
3. measuring equipment (including calibrators);
4. test site properties (test surface texture and absorption, surface gradient)

5.2 Combined standard uncertainty and resulting error due to speed inaccuracies

The value of the measurand is obtained by an interpolation of four noise values:

$$L_{urban} = (1-k_p).(1-k).L_1 + (1-k_p).k.L_2 + k_p(1-k)L_3 + k_p.k.L_4 \qquad (6)$$

Application of formula (3) with the assumption of fixed values for k_p and k then gives a standard variance of Lurban to be equal of the averaged standard variance of L1 to L4. However k is not a fixed value but is subject to measuring error caused by speed measurement inaccuracies. The value of

$$\frac{\partial f}{\partial speed} = \frac{\partial f}{\partial k} . \frac{\partial k}{\partial acceleration} \frac{\partial acceleration}{\partial speed}$$

can become quite large due to inaccuracies in the value of the Speed and therefore speed difference.

Figure 1 gives this partial factor.

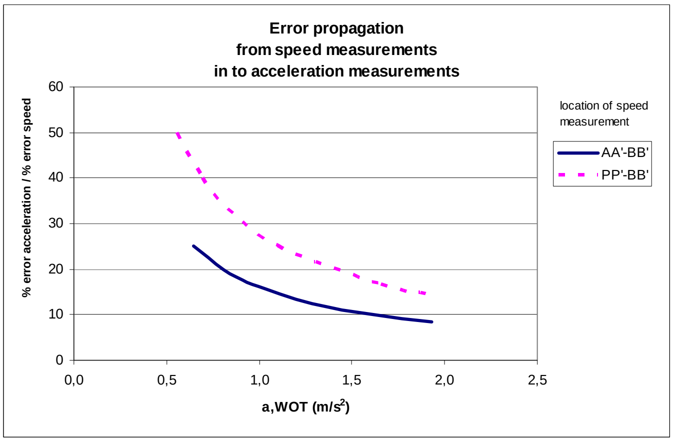

Figure 1 Worst case error propagation from speed measurements in to acceleration measurements

Figure 2 gives the total effect based on analysis of pass-by events of 40 vehicles in cases of acceleration measurement over distance A-B. This total effect reflects the worst case. We assume a normal distribution of the probability of the errors. Worst case then can be interpreted to be positioned at 2 times the standard deviation from the mean value. We calculated the worst case differences to be equal to 4 (6) times the standard deviation (+/- 2σ). In case of difference measurements over P-B the error in general increases with a factor of two, but in same cases become infinite due to non-positive values in the calculation of the acceleration.

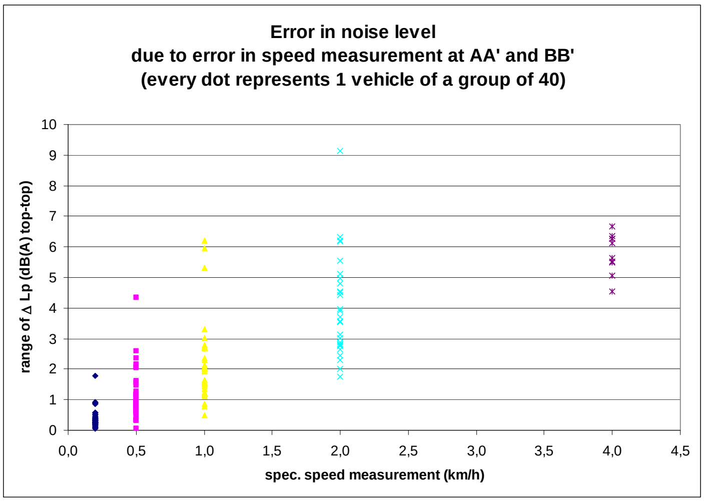

Figure 2 *Worst case error in noise level due to error in speed measurements taken at line AA' and BB'. The values of the vertical axis represents 4 (6) times the standard deviation.*

5.3 Estimated effect in practical measurements

An estimate on the effect of the most important factors is given in the table below. These data are based on various sources, including measuring experience with pass by measurements according to the former ISO362(1996) procedure and additional insights and analysis with the new procedure. New insights gained with the new measurement procedure will be necessary to define the factors more precisely.

In some cases an error is defined for one partial noise source only: rolling noise or propulsion noise. We assume that both sources contribute on average 50% to the final results and therefore the estimated value for the partial differential is 0,5).

In the definition of the accuracy of the measurements four cases are distinguished:

1. run-to-run variability: this is the accuracy in the measured result of the object defined as a certain vehicle, under certain environmental conditions driving on a certain track. (in this case the track properties and the environmental conditions and the measuring day become part of the object);
2. day-to-day variability: the accuracy in the measurement of a specific vehicle at a specific test-site. The varying environmental conditions are now a part of the error causes.
3. site-to-site variability: the accuracy statement now refers to a specific vehicle as such and all influences from environment, site etc. is part of the error causing processes.
4. vehicle to vehicle variability in which added to the site-to-site also the spread in properties within a vehicle type in included. This type of uncertainty is relevant for possible Conformity of Production checks.

table 1 sources of error when measuring vehicle pass-by

Systematic/random	cause	effect	comment	Standard uncertainty	Run-to-run:1 Day-to-day: 2 Site-to-site:3	Partial
Effects designated to ambient conditions						
rand/syst.	Barometric pressure on engine power and propulsion noise. (970-1035 mbar)	p-p: 0,5 dB (depends on engine type and motor management), major effects compensated for in the test procedure, at this moment no information on correction	normal distribution	0,125	2	0,5
Systematic	Temperature effect on tyre noise (5-40ºC)	p-p: 2 dB (will depend on tyre), after correction with general formula (see WG 27) remains a random error of 1 dB p-p, 362 does not require temperature compensation.	no correction	0,5	2	0,5
			after correction	0,25		
rand/systematic	Temperature effect on propulsion noise	p-p: 0,8 dB (depends on engine type and motor management) major effects compensated for in the test procedure, at this moment no information on correction		0,2	2	0,5
Effects designated to test site						
systematic	background noise levels	within allowed 10 dB S/N ratio an effect with 0,5 dB p-p can occur		0,125	3	1
systematic	Altitude effect is estmated to be around 120 mBar for 1000 m.	p-p: 1,0 dB (depends on engine type and motor management), major effects compensated for in the test procedure, at this moment no information on correction	very skewed distribution	0,25	3	0,5
Systematic	Track influence on tyre noise	p-p: 5 dB (will probably be reduced in new 10844, but will always be about 1 dB p-p)		1,25	3	0,5
Systematic	Track influence on propulsion noise	p-p: 2 dB (will probably be reduced in new 10844 to less then 0,5 dB p-p)		0,5	3	0,5
Random/systematic*	possible effect of gradient of track in driving direction	p-p: 1 dB (will probably be reduced in new 10844 to less then 0,5 dB p-p))		0,25	3	0,5
Effects designated to measuring equipment						
random	Sound measuring equipment. (Calibration reduces error around calibration frequency)	Class 1: systematic p-p: 1,50 dB, random 0,75 dB depending on the spectrum of the vehicle +0,1 digitizing error		0,2	1	1
				0,4	3	1
systematic	Sound calibrator	class 0: systematic p-p: 0,5 dB		0,125	3	1
random		Class 0: random 0,25 dB p-p.		0,05	2	1
Random/systematic*	Speed measuring equipment at PP'	0,2 km/h: p-p 0,2 dB		0,05	1 and 3	1
Random/systematic*	Acceleration measurement derived from speed measuring equipment	0,5% relative inaccuracy can cause +/- 20% in acceleration determination	difference A-B	0,25	1 and 3 ???	1
			differenc	0,5		

			e P-B			
Effects designated vehicle data						
systematic	Tread depth variations between 60 and 100% and aging of tyre	Depending on tyre design, 1 dB p-p	not much realiable data available	0,25	2	0,5
Effects designated run to run variability						
random	Micro climate temperature and wind effect on propagation of noise	p-p 1 dB at 5 m/s wind speed effect on individual measurements/ reduces after averaging		0,25	1	1
random	Central track (add averaging over runs)	+/- 40 (20cm) cm gives 0,4 dB p-p, reduces through avaraging		0,1	1	1
random	Speed variations of +/- 1km/h around 50 km/h	35 log v, p-p=0,6, reduces through avaraging		0,15	1	1
systematic	Varying background noise <10 dB, <15 dB	0,5 dB, 0,1 dB		0,25	1	1
random	Run to run Operating temperature of engine and tyres	p-p 0,5 dB		0,125	1	1

* random in case of driving in two directions, systematic in case of driving in one direction

6 uncertainty statement in main body

The results of the noise measurement procedure will exhibit an uncertainty due incontrollable influences on result. The sources of error and its interpretation in terms of uncertainty are based on the GUM.

Three levels of uncertainty are distinguished:

1. run-to-run variability is +/- 0,6 dB (95% coverage area)

   this is the accuracy in the measured result of the object defined as a certain vehicle, under certain environmental conditions driving on a certain track. (in this case the track properties and the environmental conditions and the measuring day become part of the object);

2. day-to-day variability is +/- 1,2 dB (95% coverage area

   the accuracy in the measurement of a specific vehicle at a specific test-site. The varying environmental conditions are now a part of the error causes.

3. site-to-site variability is +/- 1,9 dB (95% coverage area)

   the accuracy statement now refers to a specific vehicle as such and all influences from environment, site etc. is part of the error causing processes.

These values assume a acceleration measurement over A-B, In case of measuring the interval P-B the uncertainty will increase with about 0,4 dB

Annex A give an listing of the sources of uncertainty and the partial contributions to the overall variances.

(ISO 5730 ???)