Experimental approach for evaluating uncertainties associated to stationary vehicle noise according to ISO 5725

S.FICHEUX
L.F.PARDO
T.AGERON
C.BERTHOU
Introduction

Determination of uncertainties related to the standard ISO 5130 (Measurements of sound pressure level emitted by stationary road vehicles near the exhaust systems)

Analysis based on the use of the ISO 5725 approach

Uncertainties estimated on different conditions:
- run-to-run (with several operators)
- day-to-day (Atmospheric condition)
- site-to-site (surface condition)
- vehicle to vehicle
European regulation (directive 1999/101/CE and the regulation 51 rev02) presents two acoustical tests:

- A dynamic test which is subject to limit
- A stationary test

The stationary test is also used by national authorities to control vehicle in use:

- Spot test by police
- Periodical test by technical inspection facilities

The stationary test is based on the international standard ISO 5130

French regulation allows a 5 dB divergence between type approval and in use test values
Measuring procedure

Vibration tachymeter

Reference value (type approval test)
80 dB(A) at 3000 rpm

Microphone with analyser or sound meter (IEC 60651)

Microphone position
Conditions of engine operation:
- Engine speed stabilized at a reference value
- Throttle rapidly returned to the idling position.

Conditions of acoustical measurement:
- Sound level measured over this operating period
- Maximum sound-level meter reacting being taken as the test result (dB(A) – FAST)
- Three measurements
- Final result is the mean these 3 values
The arborescence can be different from vehicle to vehicle or surface to surface or meteorological condition to meteorological condition.
Estimation of the uncertainty of measurement

• Definition
• GUM approach
• ISO 5725 approach
• Estimation of the range which contains the true value (VIM 1984)

• Parameter, associated with the result of a measurement that characterizes the dispersion of the value that could reasonably be attributed to the measurement (VIM 3.9 1993)
• Coverage interval: GUM 2.3.5 "interval that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand.

\[ [y - ku_c(y), y + ku_c(y)] \]
Two approaches

- "GUM approach"
- "ISO 5725 approach"

These two approaches are complementary and are not exclusive. In both cases variances estimates are calculated. Furthermore it’s possible to use the two approaches together.
The model

\[ Y = f(X_1, X_2, \ldots, X_n) \]

Y is determined from n other quantities

Representation of a process of measurement

First-order Taylor series approximation

\[
\sigma_Y^2 = \sum_{i=1}^{n} \left( \frac{\partial f}{\partial X_i} \right)^2 \sigma_{X_i}^2 + 2 \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \frac{\partial f}{\partial X_i} \frac{\partial f}{\partial X_j} \rho_{ij} \sigma_{X_i} \sigma_{X_j}
\]
• It is necessary to find the functional relationship f
• Not exhaustive
• suited for metrology/calibration rather than tests laboratories
• Ascending approach
• Accuracy of measurement method.
  – Precision
  – Trueness
• **Precision**: the closeness of agreement between independent test results obtained under stipulated conditions.
  
  – **Repeatability**: precision under repeatability conditions, expressed by a standard deviation.
  – **Reproducibility**: precision under reproducibility conditions expressed by a standard deviation.

• **Trueness**: the closeness of agreement between the average value from a large series of test results and an accepted reference value.
  
  – The measure of trueness is expressed in terms of bias
• Model of analysis of variance:

\[ Y_{ij} = m + L_i + \varepsilon_{ij} \]

where

- \( Y_{ij} \) jth test result from laboratory i,
- \( m \) general mean,
- \( L_i \) laboratory effect i, i=1 to p, with variance \( \sigma^2_{L} \),
- \( \varepsilon_{ij} \) residue on the jth result from laboratory i, j = 1 to n, with variance \( \sigma^2_{\varepsilon} \).
## ISO 5725 approach (5)

<table>
<thead>
<tr>
<th>Effects</th>
<th>Sum of square</th>
<th>Degree of freedom</th>
<th>Mean square</th>
<th>Expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laboratory</td>
<td>[ \sum_{i=p}^{i=n} \sum_{j=1}^{j=n} (\bar{y}_i - \bar{y})^2 = B ]</td>
<td>( p - 1 )</td>
<td>[ \sum_{i=1}^{i=n} \sum_{j=1}^{j=n} (\bar{y}_i - \bar{y})^2 / p - 1 ]</td>
<td>( n\sigma_L^2 + \sigma_\varepsilon^2 )</td>
</tr>
<tr>
<td>Residual</td>
<td>[ \sum_{i=1}^{i=n} \sum_{j=1}^{j=n} (y_{i,j} - \bar{y}_i)^2 = W ]</td>
<td>( np - p )</td>
<td>[ \sum_{i=1}^{i=n} \sum_{j=1}^{j=n} (y_{i,j} - \bar{y}_i)^2 / np - p ]</td>
<td>( \sigma_\varepsilon^2 )</td>
</tr>
<tr>
<td>Total</td>
<td>[ \sum_{i=1}^{i=n} \sum_{j=1}^{j=n} (y_{i,j} - \bar{y})^2 = T ]</td>
<td>( np - 1 )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ T = B + W \]
• Precision evaluation:
  – Repeatability standard deviation: \( \sigma_r = \sigma_e \)
  – Reproducibility standard deviation: \( \sigma_R = \sqrt{\sigma_e^2 + \sigma_L^2} \)

⇒ Variance components estimation
\[
S_r = s_e \quad \quad S_R = \sqrt{s_e^2 + s_L^2}
\]

• Trueness evaluation:
  – \( \delta = m - \mu \) where \( \mu \) is the reference value when it exists.
  – Estimated by: \( \hat{\delta} = \hat{m} - \mu \)
• Our model is more complicated

\[ y_{ijklm} = \mu + V_i + AC_j(V_i) + TS_k(AC_j(V_i)) + O_1(TS_k(AC_j(V_i))) + \varepsilon_{ijklm} \]

\( y_{ijklm} \) represents the value of the studied characteristic of the \( m \)th repetition for the \( l \)th operator of \( k \)th test surface of \( j \)th atmospheric condition of \( i \)th vehicle,

\( \mu \) the effect due to \( i \)th vehicle, presumed distributed according to a Laplace-Gauss distribution with mean 0 and variance \( \sigma^2_V \)

\( AC_j(V_i) \) effect due to the \( j \)th atmospheric condition of \( i \)th vehicle, presumed distributed according to a Laplace-Gauss distribution with mean 0 and variance \( \sigma^2_{AC} \)

\( TS_k(AC_j(V_i)) \) \( \sigma^2_{TS} \)

\( O_1(TS_k(AC_j(V_i))) \) \( \sigma^2_O \)

\( \varepsilon_{ijklm} \) residue of the \( m \)th repetition for the \( l \)th operator of \( k \)th test surface \( j \)th atmospheric condition of \( i \)th vehicle, with mean 0 and variance \( \sigma^2_\varepsilon \)
ISO 5725 approach (8)

- Estimation of the variance components

\[ s_r = s_\varepsilon \]

\[ s_{f1(1)} = \sqrt{s_r^2 + s_o^2} \]

\[ s_{f1(2)} = \sqrt{s_r^2 + s_O^2 + s_{TS}^2} \]

\[ s_{f(3)} = \sqrt{s_r^2 + s_O^2 + s_{TS}^2 + s_{AC}^2} \]

\[ s_R = \sqrt{s_r^2 + s_O^2 + s_{TS}^2 + s_{AC}^2 + s_V^2} \]
• the combined standard uncertainty $u_c(y)$ comes from the values of precision:

- in conditions of repeatability, $u_c(y) = s_r$
- in conditions of intermediate precision, $u_c(y) = s_{fi}$
- in conditions of reproducibility $u_c(y) = s_R$

• the expanded uncertainty $U = k \times u_c(y)$
ISO 5725 approach (10)

<table>
<thead>
<tr>
<th>studied characteristic</th>
<th>Stationary Noise (in dB(A))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard deviation of repeatability, with constant vehicle, atmospheric condition, test surface and operator</td>
<td>0.3</td>
</tr>
<tr>
<td>Limit of repeatability, with constant vehicle, atmospheric condition, test surface and operator</td>
<td>0.8</td>
</tr>
<tr>
<td><strong>Expanded uncertainty in conditions of repeatability, with constant vehicle, atmospheric condition, test surface and operator</strong></td>
<td><strong>0.6</strong></td>
</tr>
<tr>
<td>Intermediate standard deviation of precision, with constant vehicle, atmospheric condition and test surface, whatever the operator</td>
<td>0.4</td>
</tr>
<tr>
<td>Intermediate limit of precision, with constant vehicle, atmospheric condition and test surface, whatever the operator</td>
<td>1.1</td>
</tr>
<tr>
<td><strong>Expanded uncertainty in conditions of intermediate precision, with constant vehicle, atmospheric condition and test surfaces, whatever the operator</strong></td>
<td><strong>0.8</strong></td>
</tr>
<tr>
<td>Intermediate standard deviation of precision, with constant vehicle and atmospheric condition, whatever the test surface and the operator</td>
<td>0.5</td>
</tr>
<tr>
<td>Intermediate limit of precision, with constant vehicle and atmospheric condition, whatever the test surface and the operator</td>
<td>1.5</td>
</tr>
<tr>
<td><strong>Expanded uncertainty in conditions of intermediate precision, with constant vehicle and condition atmospheric, whatever the test surface and the operator</strong></td>
<td><strong>1.1</strong></td>
</tr>
<tr>
<td>Intermediate standard deviation of precision, with constant vehicle, whatever the atmospheric condition, the test surface and the operator</td>
<td>0.5</td>
</tr>
<tr>
<td>Intermediate limit of precision, with constant vehicle, whatever the atmospheric condition, the test surface and the operator</td>
<td>1.5</td>
</tr>
<tr>
<td><strong>Expanded uncertainty in conditions of intermediate precision, with constant vehicle, whatever the atmospheric condition, the test surface and the operator</strong></td>
<td><strong>1.1</strong></td>
</tr>
<tr>
<td>Standard deviation of reproducibility, whatever the vehicle, the atmospheric condition, the test surface and the operator</td>
<td>1.0</td>
</tr>
<tr>
<td>Limit of reproducibility, whatever the vehicle, the atmospheric condition, the test surface and the operator</td>
<td>2.8</td>
</tr>
<tr>
<td><strong>Expanded uncertainty in conditions of reproducibility, whatever the vehicle, atmospheric condition, the test surface and the operator</strong></td>
<td><strong>2.0</strong></td>
</tr>
</tbody>
</table>
• Better suited for test laboratories
  – use of the data which are available
  – use of the precision value issued from interlaboratories test

• Descending approach
Thank you for attention
Standardization works

- ISO/TC 69/SC 6
  - WG 1 Accuracy of measurement methods and results
  - WG 5 Limits of determination
  - WG 7 Statistical methods to support measurement uncertainty evaluation.

- JCGM/WG1
  - WG1 Measurement uncertainty (VIM GUM)
Bibliography

Experimental results
Measurand, Error, Uncertainty

- Measurand's values
- Error
- Uncertainty

(observed value) « true value "

Measurand’s values
ISO 5725 approach (3)

- Repeatability of the standard measurement method of labo 1
- Bias of the standard measurement method of labo 1
- Bias of the standard measurement method
- Repeatability of the standard measurement method of labo 2
- General mean
- Mean of labo 1
- Labo 2
- Reproducibility of the standard measurement method
- True value or reference value