September 2018

PRESENTATION OF

INTERNATIONAL ORGANIZATION OF MOTOR VEHICLE MANUFACTURERS

Additional Sound Emission Provisions 2.0

Introduction of the Sound Emission Prediction Model

GRB Informal Working Group ASEP #9

ASEP Revision 2.0 - Expectations

Contracting Parties	Automotive Industry

➢ Improve efficiency of ASEP
➢ ASEP shall become mandatory during Type Approval
➢ Broaden the boundary conditions
➢ Check need for
  ➢ Defeat device provisions
  ➢ Not to Exceed Concepts (NTE)
	➢ Simplify ASEP
	➢ Reduce work load
	➢ Safe qualification about ASEP compliance, especially with “normal” products
	➢ ASEP shall follow physics

ASEP Concept Based on a Physical Expectation Model

- A compromise between an extended test area and a reduced test burden is feasible, when tests are selected randomly and when after each individual test run a direct compliance assessment is available.
- Already existing elements of the today's ASEP assessment are integrated into a new approach:

Physical Behavior
(Origin: „Slope Method")

Direct Assessment
(Origin: „L_{urban} Method")

Based on Annex 3 Results
(Origin: „Slope & L_{urban} Method")

Engine Speed Based
(Origin: „Slope Method")

Direct assessment based on a physical expectation model, referenced to the type approval result of Annex 3

To be Solved: How to treat BEV, HEV

Sound Prediction Model - Basic Considerations

1 Tyre

2 Base Mechanic

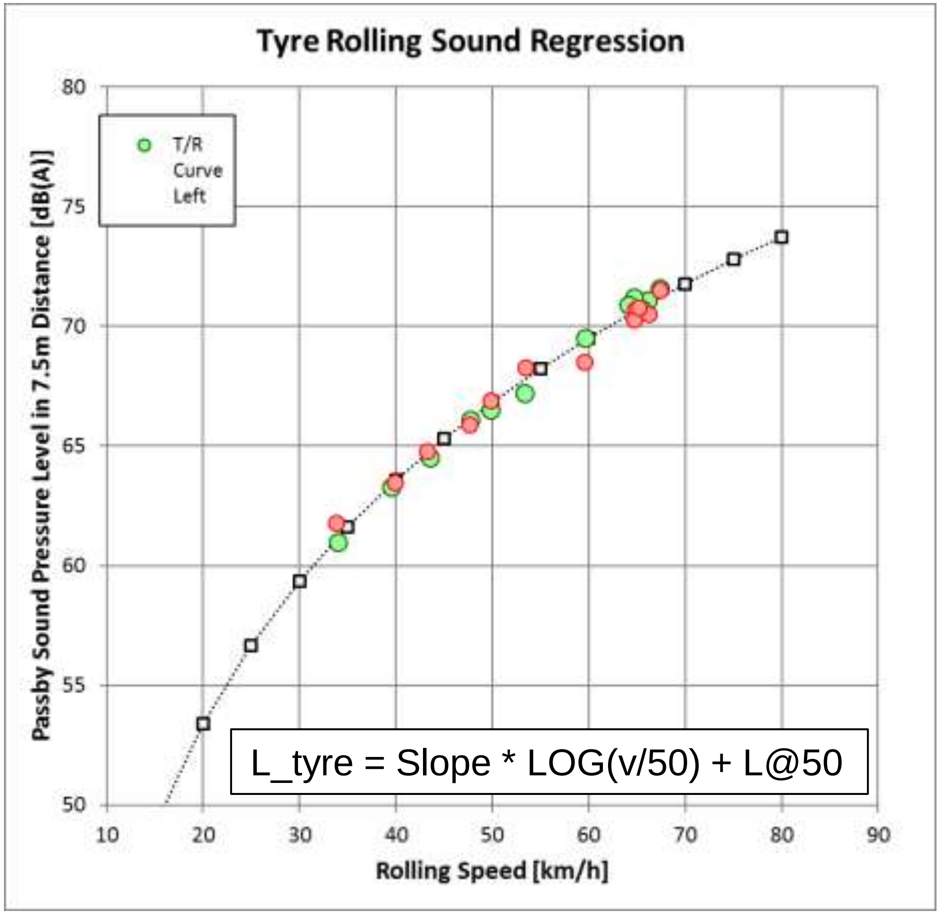
- The two elements together create the "physical" base model for a behavior of any internal combustion engine vehicle.
- These two models will form the minimum sound emission of a vehicle.
- This sound emission is given by physics an qualified / justified by the type approval test according to Annex 3 and controlled by the limit values.

3 Dynamic

- The dynamic model covers all sound behavior, that is linked to acceleration (load) conditions
- It covers tyre torque effects, powertrain dynamics and gas flow dynamics.

1 Tyre Rolling Sound Modelling

1 Tyre Rolling Sound - Modelling



- Tyre rolling sound can be described with good accuracy by a logarithmic regression.
- Tyres may as well have smaller resonances, by the typical deviation from the regression is rather small.
- Typical regression qualities are $R^2 > 0.98$

1 The "Prediction Model" for the Tyre Rolling Sound

- The mathematical function is:

$$L_{TR,NL} = slope_{TR} * LOG_{10}(v_{test} / 50) + L_{REF,TR}$$

There will be a **$slope_{TR,min}$** for test speeds below 50 km/h and a **$slope_{TR,max}$** for speeds above 50 km/h.

The differentiation accounts for the unknown behaviour of the tyre rolling sound.

The **$L_{REF,TR}$** is a fraction of the steady speed test result of Annex 3 **$L_{CRS,i}$**.

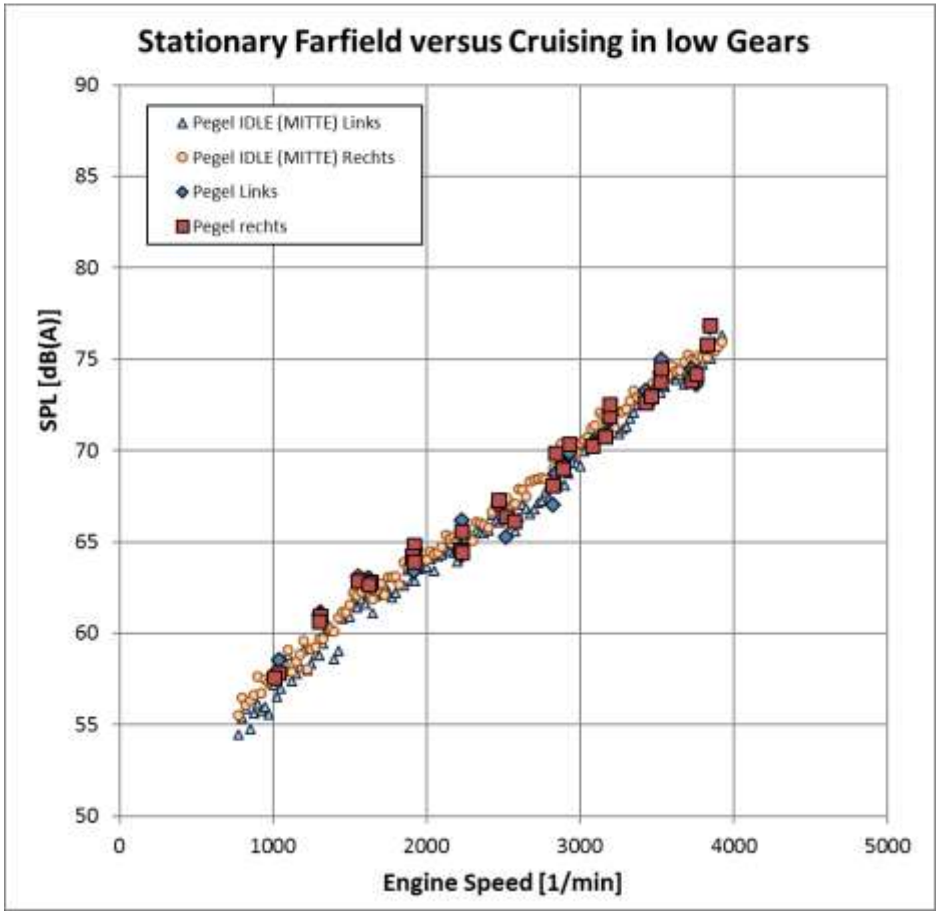
$$L_{REF,TR} = 10 * LOG_{10}(x\% * 10^{(L_{crs,i}/10)})$$

How much percent (**x%**) of the steady speed result is used, needs further investigation and might be defined differently for the vehicle categories.

The tyre rolling sound's load dependency is covered under the dynamic model 3 .

2 Power Train Base Sound Modelling

2 Base Mechanic - Modelling



- For determination of the power train base mechanic, there are two possibilities:
  - stationary run-up in far field
  - cruise-by measurements at low gears, e.g. 1st gear
- It is important to eliminate the influence of the tyre rolling sound and to suppress any gas flow dynamics.
- Both methods provide almost the same result and can be used to elaborate the powertrain base mechanic model.

2 The "Prediction Model" for the Power Train (No Load)

- The mathematical function is:

$$L_{PT,NL} = slope_{PT,NL} * LOG_{10}(n_{test} + n_{shift}) / (n_{wot,ref} + n_{shift})) + L_{REF,NL}$$

A $slope_{PT,min}$ for test engine speeds below $n_{BB',REF}$ and a $slope_{PT,max}$ for speeds above $n_{BB',REF}$ is introduced.

The differentiation accounts for the unknown behaviour of the power train.

An engine speed shift component n_{shift} is introduced for an optimized curve fitting for the power train model

The parameter $L_{REF,NL}$ is the remaining part of the steady speed test of Annex 3 $L_{CRS,i}$ that was not used in the tyre model before.

$$L_{REF,NL} = 10*LOG((100\%-X\%)*10^{(LCRS,i/10)})$$

The power train base mechanic's load dependency is covered under the dynamic model (3) .

3 Power Train Dynamic Modelling

3 The Dynamic Model

- The dynamic model covers all energy generated under load, respectively acceleration:
  a) All gas flow components (intake and exhaust), no load and load
  b) Change of the power train mechanic sound with the load
  c) Tyre torque effects
- The load response from the power train and the torque effect are relatively small compared to the gas flow components from intake and exhaust.

3 The Dynamic Model

- The mathematical function is:

$$L_{DYN} = slope_{DYN,NL} * LOG_{10}((n_{test} + n_{shift})/(n_{wot,ref} + n_{shift})) + L_{REF,DYN,NL} + \Delta L_{DYN}$$

A **$slope_{DYN,min}$** for test engine speeds below **$n_{BB',REF}$** and a **$slope_{DYN,max}$** for speeds above **$n_{BB',REF}$** is introduced.

The differentiation accounts for the unknown behaviour of the power train.

$$n_{BB',REF} = n_{BB',WOT,i}$$

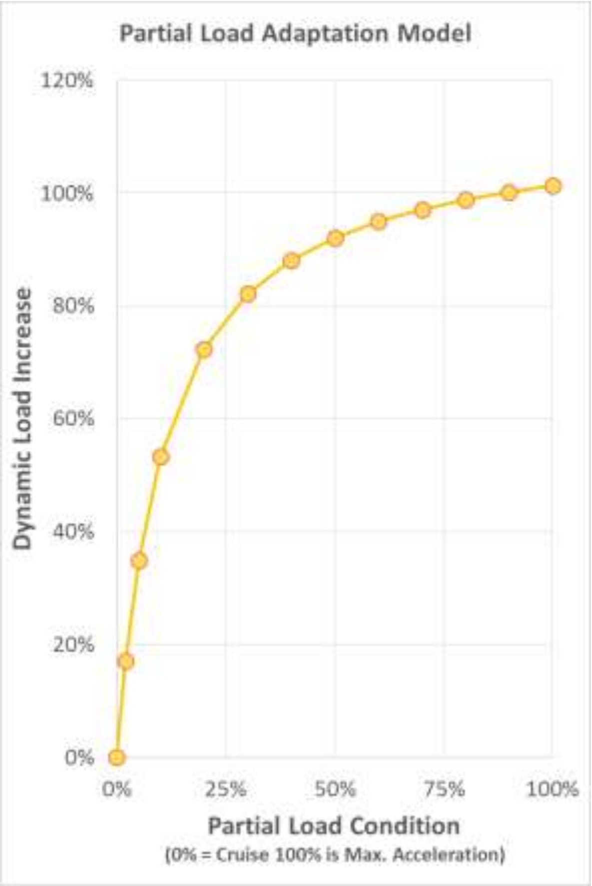
An engine speed shift component **n_{shift}** is introduced for an optimized curve fitting for the dynamic model

See next slide

See next slide

3 The Partial Throttle Model

- For a full dynamic model it is necessary to consider a partial throttle model.
- One difficulty is, that for many situations an already partially opened throttle means already full throttle.
- While we consider in Annex 3 that the link between the constant speed test and the acceleration test is linear, we need for ASEP a different model with a high increment from low throttle positions and a 90% load saturation at 50% throttle condition.
- Another difficulty is the question, how to determine the partial throttle condition.
  - This is most correctly done, by the determination of the position of the accelerator. His is design neutral and more accurate compared to the control of the throttle opening
  - Alternatively, this might be determined by the determined acceleration relative to the maximum acceleration of a given gear or gear ratio.
- Here is more research needed.
- As a simplification, one might apply the full throttle curve as well to any partial throttle conditions.



$\Delta L_{partial}$ = (1-0,111/(0,111+Load%/100)/(1-0,111)

Integration of all Modules

- Before the ASEP evaluation, it is necessary to carry out the Annex 3 type approval test
  - The parameter to be reported are: L_{wot} and L_{crs} from the lower or single gear, the acceleration (actually PP-BB), the vehicle speed v_{BB}, the engine speed n_{BB}.
  - For the gear ratio, the maximum acceleration must be known to determine the load condition.

- The expectation level is then calculated

$$L_{exp} = 10 * LOG\left(10^{0,1*L_{TR,NL}} + 10^{0,1*L_{PT,NL}} + 10^{0,1*(L_{DYN,NL} + \Delta L_{DYN})}\right) + \Delta L_{MARGIN}$$

- Compliance is achieved when

$$L_{test}(v_{test}, a_{test}, n_{test}) \leq L_{exp}(v_{test}, a_{test}, n_{test})$$