ECE R41.04 – MEASUREMENT OF ACCELERATION NOISE LEVEL OF MOTORCYCLES

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ABSTRACT

The control of sound pollution, mainly in large cities, must be encouraged, legislated and inspected increasingly. The vehicle noise emission is one major international concern in the field of vehicle environmental regulation programs, such as the European EURO [1], which has been revising and improving its procedure over the years, being, in this context, the main world reference.

This article has the purpose to present the methodology and results of noise level measurements under ECE R41.04 [2]**,** European standard for category L3 vehicles. This standard was developed according to real traffic measurements with motorcycles, focusing on urban streets behavior to maximize the real conditions into the test procedure for vehicle approval. It is possible to demonstrate the current disharmony between the European vehicle environmental program and the Brazilian PROMOT [3], which it concerns to noise regulation.

A similar study was made to light vehicles that revised the methodology of ISO 362 [4] standard and Brazilian PROCONVE [5] program adopted it, however, the same methodologic criteria is not observed in PROMOT. At the end, acceleration noise results, measured according to ECE R41.04, are presented and compared with the results of the current ABNT NBR 15145 procedure.

INTRODUCTION

1. CURRENT INTERNATIONAL STANDARD

TIMELINE

Vehicle noise is one of the main regulated themes all around the world, considering the big impact in the human health. Focusing to the motorcycles, the major spotlight of regulation is the European Union (EU) through the United Nations Economic Commission for Europe (UNECE) Sustainable Transport Division, which managers the famous World Forum for the Harmonization of Vehicle Regulations, commonly known as WP.29.

Dedicated to automotive regulation, the WP.29 has several expert groups to study and issue the main requirements and performance or construction specifications that a vehicle must comply. These regulations are the UN Regulations, also known as ECE Regulations.

Regarding to motorcycle noise, the current European regulation is the ECE R41 – *"Uniform provisions concerning the approval of motorcycles with regard to noise"* [2], which nowadays is in its 04 series of changes. Each series indicates that a great amendment in the requirement occurred.

The first version of ECE R41 was stablished in 1980, and, over the years, it has been improved by the experts. The table below shows the timetable of ECE R41.

Table 1. Timetable of ECE R41

Regulation number	Amendments and corrections	Revision	Date of entry into force
R41 - MOTORCYCLE SOUND LEVELS	R41.00		01/06/1980
	R41.01		24/07/1984
	R41.02		01/04/1994
	Correction 01	01	25/06/2008
	R41.03		05/02/2000
	Supplement 01		10/10/2006
	R41.04	02	13/04/2012
	Supplement 01		09/10/2014
	Supplement 02		08/10/2015
	Supplement 03		20/01/2016
	Supplement 04		08/10/2016
	Supplement 05		09/02/2017
	Supplement 06		16/10/2018
	Supplement 07		15/10/2019

BASE STUDY FOR ECE R41.04

Until the 03 series of ECE R41, the test procedure to measure acceleration noise of the motorcycles were constituted by a full throttle acceleration in a test site.

The motorcycle with manual transmission shall always be tested either 2nd and/or 3rd gear, depending on the engine displacement and maximum engine speed obtained during the test.

The maximum sound level captured by microphones when the motorcycle passes at full throttle acceleration, should be under the specified limits, depending on the series. In order to have different

classifications, the categories of motorcycles were determined according to engine capacity (cc) until the 03 series.

Table 2. Evolution of ECE R41 limits.

ECE R41 Evolution – Maximum Sound Level Limits				
Date	1980	1985	1995	2000
Engine capacity (cc)	R41.00	R41.01	R41.02	R41.03
≤80	78	77	75	75
>80 ≤125	80	80	77	77
>125 ≤175	83	80	77	77
>175 ≤350	83	82	80	80
>350 ≤500	85	82	80	80
>500	86	82	80	80

The full throttle acceleration test was widely used over the years not only for motorcycles, but also for light passenger vehicles that had the same procedure, prescribed by ECE R51 [6]. However, it was noticed that this test procedure was not being effective because it does not reflect the real conditions, as described by the Commission Directive 2007/34/EC [7], on June 14th, 2007:

> *"Since the entry into force of Directive 70/157/EEC of 6 February 1970, the noise limits for motor vehicles have been reduced several times, most recently in 1995. The last reduction did not have the expected effects and subsequent studies have shown that the measurement method no longer reflects the real-life driving behavior. It is therefore necessary to introduce a new test procedure and bring the driving conditions for carrying out the noise test closer into line with real life driving operations. The new test cycle is contained in UN/ECE Regulation No 51, 02 series of amendments (Commission of the European Communities, 2007)"*

The above description is related to light vehicles and ECE R51 standard, but it can be also extended to other kind of vehicles, including the motorcycles. Thus, the revision of test procedures of noise test was started, initially for ECE R51 and consequently for R41.

To change the test methodology of ECE R41.03, the following motivations were considered:

- The current procedure at the time (ECE R41.03), was not based on data that come specifically from motorcycles, but from four-wheeled vehicles;
- The real operation mode of motorcycles, especially in cities, is not full but in a partial acceleration operation;
- The new test should be closer to the real driving conditions.

These principles would maximize the real effects of the maximum sound level limits in the motorcycle projects, bringing a positive benefit to the environment in general.

In the extensive base study made by the experts of WP.29 [8] to revise the ECE R41, actual motorcycle driving data obtained since 1998 during the technical development of the World Motorcycle Test Cycle (WMTC) [9], the international test cycle for exhaust emission determination for motorcycles, was used. In this study, a detailed analysis of the motorcycle behavior in the streets was observed.

Using a sampling of 48 vehicles, 851 real trips in also urban, suburban, rural and highway conditions were carried out at the regions below:

- EUROPE (Amsterdam, Frankfurt, Mandeure, Munich, Paris, Pisa, Stuttgart);
- USA (Birmingham, AL);
- JAPAN (Tokyo, Tsuchiura, Tsukuba).

The distributions of the runs are as below:

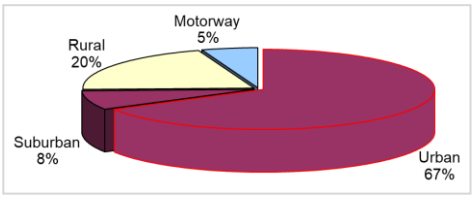

Figure 1. Distribution of types of areas.
Source: (United Nations Economic Commission for Europe, 2020)

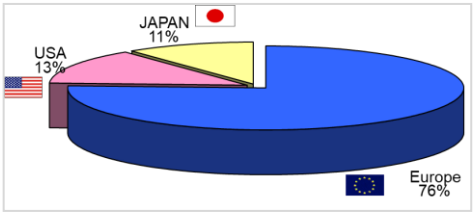

Figure 2. Distribution of regions.
Source: (United Nations Economic Commission for Europe, 2020)

As one of the first premises, the categories divisions should no longer be by engine capacity, but through the Power-to-Mass Ratio (PMR). This would better represent the specific individual characteristic of each motorcycle.

Analyzing the WMTC database, the vehicle speeds ranges that are most closely associated with typical motorcycle usage in urban areas were defined as the Figure below shows the frequencies distribution of the speed.

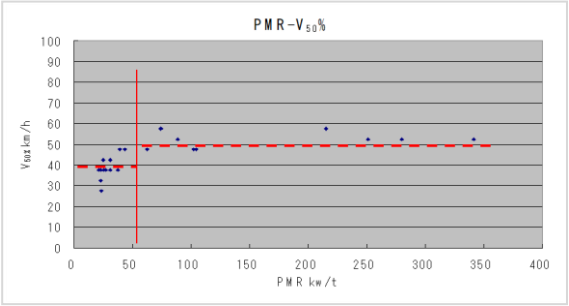

Figure 3. Distribution of speed by PMR.
Source: (United Nations Economic Commission for Europe, 2020)

As represented by the Figure above, the average speed range below 50 PMR is around 40 km/h and for

PMR above 50, the average speed is 50 km/h, demonstrating a slight difference in the behavior of small motorcycles to the others. Besides, the acceleration curves for PMR above and below 50 are also distinct, creating a necessity of cut-off.

The Figure below indicates the acceleration curves for full throttle and urban behaviors according to the PMR.

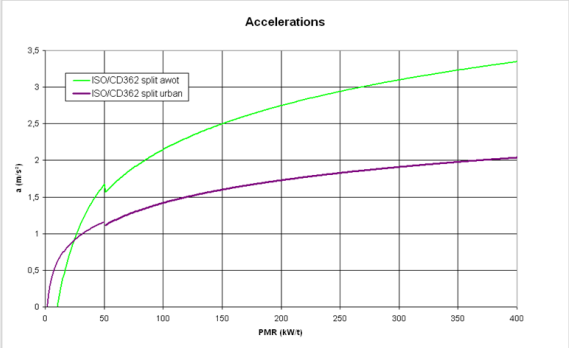

Figure 4. Acceleration curves according to PMR.
Source: (United Nations Economic Commission for Europe, 2020)

The acceleration curve of urban driving behavior, calculated individually by each PMR, made the test procedure of ECE R41.04 much closer to reality. The figure below shows an approximation of the real behavior of the engine speed (rpm) and opening throttle of motorcycles distributed in a heat chart. Moreover, is possible to analyze the coverage of ECE R41.03 procedure, which tests with 100 % of throttle (full). Comparing to the same motorcycle being tested with ECE R41.04, the coverage is closer to the real distribution, attesting that the method is more faithful.

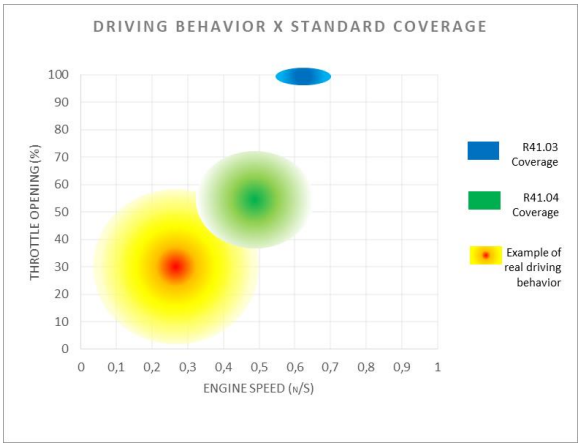

Figure 5. Example of regular motorcycle driving behavior and standards coverage.

Regarding maximum limits, the revision of the methodology of ECE R41.03 to R41.04 did not aim to reduce limits, but rather prioritized the improvement in the procedure and the test, as well as maintaining the margins within the limits of the current models. However, at the end of the discussions, the proposed margin (Standstill) was further reduced by 1 dB (A).

The Figure 6 below shows the comparison of some motorcycles at that time tested according to ECE R41.03 and R41.04.

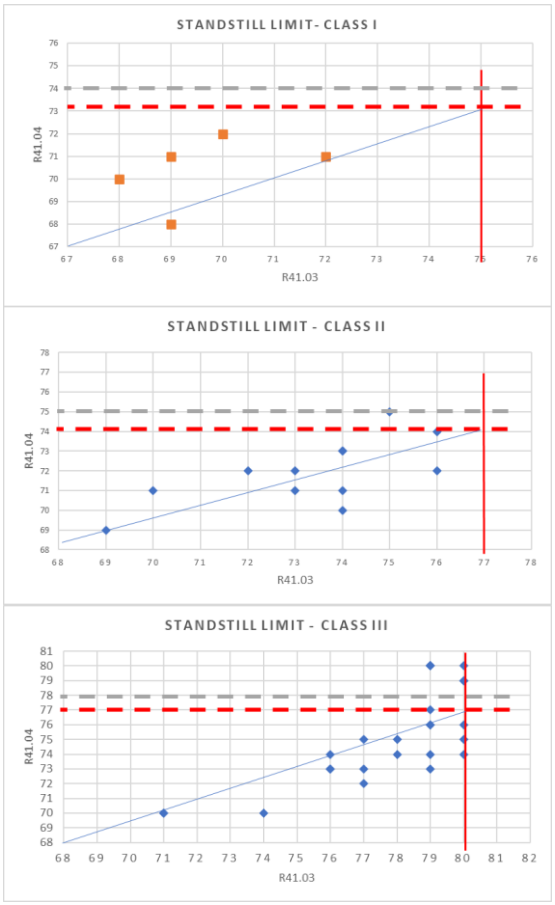

Figure 6: Comparison graphs ECE R41.03 and R41.04.
Source: (United Nations Economic Commission for Europe, 2020)

METHODOLOGY

After the study made by the experts of WP.29, it was consensus that the method should be designed with the consideration of noise level result obtained by a full throttle operation (wot) and the result obtained by a constant speed operation (CRS), in order to have an approximation of the real urban drive condition.

The test site stablished by ECE R41.04 is basically the same of the previous series, considering the same microphones positions, distances, and meteorological conditions requirements. The test site is defined below:

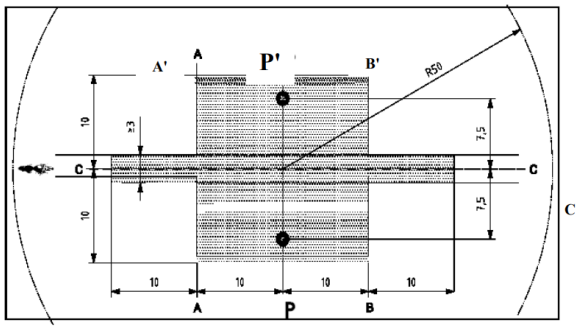

Figure 7. Test site for noise procedure.

Source: (UNITED NATIONS, R41.04: Uniform provisions concerning the approval of motor cycles, 2012)

The differences incorporated in the 04 series are the virtual line PP', where the vehicle speed (vPP') and the engine speed (nPP') must be measured, corresponding to the point in time when the front of the vehicle passes the line PP'. These measurements were not needed in the previous series of R41.

A basic flowchart considering the main steps of the acceleration test is described below.

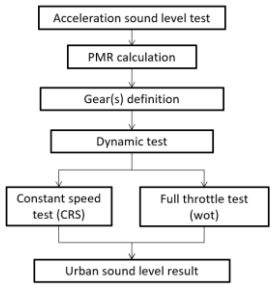

Figure 8. Noise test flowchart.

First of all, it is necessary to calculate the power-to-mass ratio (PMR) of the vehicle.

After the PMR definition, the first practical step is the gear(s) determination. As previously observed in the base study for the standard, in the 04 series is stablished that each vehicle will always have a different test condition, specific for its defined PMR. To determine the correct gear(s) to be tested, is necessary to perform several practical runnings with all gears, with the excemption of the first gear, observing the target vPP' speed.

After that, the gear that better correspond to the reference accelaration $a_{wot\ ref}$ is designed for the test.

For the acceleration test, the vehicle, engaged in the determined gear, must approach the line AA' at constant speed and perform as fast as possible a full throttle acceleration to aim the designed vehicle speed (40 or 50 km/h) at line PP'. This acceleration must be kept until the end of the test at line BB'.

For the constant speed test, the same gear(s) shall be used, maintaining the designed vehicle speed (40 or 50 km/h) constantly between the lines AA', PP' and BB'.

The results of the sound levels, measured in the sound scale "A", are reduced in 1 dB(A) and an arithmetical average is made, resulting in the full throttle acceleration sound level L_{wot} and the constant speed sound level $L_{crs.}$

At the end, the ponderation of the L_{wot} and L_{crs} is made by the partial power factor k_p, which is a weighting factor result of a calculation of the corresponding target urban acceleration a_{urban} and the real test full throttle acceleration $a_{wot(i)}$ or the reference acceleration $a_{wot\ ref}$ in the case of two gears test, according to the below.

Kp for two gears test:

$$k_p = 1 - (a_{urban} / a_{wot,ref}). \quad (1)$$

Kp for single gear test:

$$k_p = 1 - (a_{urban} / a_{wot,(i)}) \quad (2)$$

The finnal result is the L_{urban} sound level, which represents the urban driving noise.

$$L_{urban} = L_{wot} - k_p * (L_{wot} - L_{crs}) \quad (3)$$

REGULATED LIMITS

The sound level limits are determined according to the PMR classification as below:

Table 3. Sound level limits of ECE R41.04

Power-to-mass ratio index PMR	Limit value L_{urban} in dB(A)
PMR ≤ 25	73
25 < PMR ≤ 50	74
PMR > 50	77

ASEP – ADDITIONAL SOUND EMISSION PROVISIONS

Beyond the method prescribed, the ECE R41.04 brought as innovation for motorcycles regulation the Additional Sound Emission Provisions (ASEP), which gives the inspector the possibility to request more tests (or runs) in the type approval of motorcycles with PMR above than 50 with different conditions, such other speeds and/or engine speeds.

The objective is to guarantee the conformity beyond the regular procedure, mainly with the vehicle in high speeds and high engine speeds, minimizing the possibility of software manipulation and the use of defeat devices.

> *"The motorcycle manufacturer shall not intentionally alter, adjust, or introduce any device or procedure solely for the purpose of fulfilling the noise emission requirements of this Regulation, which will not be operational during typical on-road operation. (UNITED NATIONS, 2012)"*

The possibilities by ECE R41.04 are:

a) $v_{AA'}$ shall be at least 20 km/h;
b) $v_{BB'}$ shall not exceed 80 km/h;
c) $n_{AA'}$ shall be at least 0.1 x (S – n_{idle}) + n_{idle};
d) $nB_{B'}$ shall not exceed:
   a. 0.85 x (S – n_{idle}) + n_{idle} for PMR < 66 and
   b. 3.4 * PMR-0.33 x (S – n_{idle}) + n_{idle} for PMR > 66

In particular, the ASEP establishment defines a new possibility not only for manufacturers, but also for environmental agencies, to understand the noise behavior of some vehicle in other patterns different from the regular test demands, creating an expansive base data and making possible a wide study for a possible future review of the test procedure.

The possibility to obtain different data of sound level allows the continuous improvement for the future.

2. GENERAL REGULATION DISHARMONY

EURO/PROMOT PROGRAMS EVOLUTION

The European program of vehicle approval, known as EURO, managers for a long time all the characteristics that a motorcycle must comply and guarantee before the production and selling, such as safety requirements, construction and especially environmental regulation. In this field of application, two items are highlighted: exhaust emission and sound level.

In Brazil, a similar program related to environment protection is the PROCONVE, for automobiles, and PROMOT, for motorcycles and similar vehicles. The PROMOT, as well as the EURO, has also exhaust emission and sound level requirements regulated. As the European program is the worldwide highest level of regulation, the Brazilian PROMOT always took the requirements, standard and limits of EURO as technical base for the national rules, allowing the harmonization of the legislations.

Nowadays, the European program is in its 5th step of evolution, known as EURO 5. Regarding sound level regulation, the program stablished the ECE R41.04 since EURO 4, which entered into force in 2016.

Brazil has just issued the new legislation CONAMA Resolution 493/2019, stablishing the future PROMOT M5 entering firstly in 2023 for new model development and 2025 for all models to be manufactured.

The figure below indicates the schedules of EURO and PROMOT evolution according to the time.

Figure 9. Schedule of PROMOT and EURO.

PROMOT M5 – HARMONIZATION

As mentioned before, the PROMOT has always allowed the harmonization with EURO requirements along the time, especially for exhaust emission, however, the PROMOT, since PROMOT M4 and recently with PROMOT M5, let the sound level regulation out of harmony with EURO, maintaining the use of the standard ABNT NBR 15145 - *Acoustics - Measurement of noise emitted by accelerating road vehicles - Engineering method.* [10]

The Brazilian standard is based in the ECE R41.03, which was the ECE standard in force at the time of NBR development, however, the R41 evolved a lot since then.

Analyzing directly all the requirements of PROMOT M5 and EURO 5, is possible to see that only sound level regulation is out of harmonization.

Table 4. PROMOT M5 and EURO 5 comparison

Requirement	BRAZIL	EUROPE	OBS
Exhaust Emission WMTC	PROMOT M5	EURO 5	Harmonized / Same requirement
Idle Exhaust Emission	PROMOT M5	EURO 5	Harmonized / Same requirement
Evaporative Emission SHED	PROMOT M5	EURO 5	Harmonized / Same requirement
Permeability Evaporative Emission	PROMOT M5	EURO 5	Harmonized / Same requirement
Durability of emissions	PROMOT M5	EURO 5	Harmonized / Same requirement
OBD-I e OBD-II	PROMOT M5	EURO 5	Harmonized / Same requirement
Noise level	**PROMOT M4**	**EURO 5**	**Out of harmonization**

Besides the technical difficulties that the disharmony brings, not only for industries, but also for technical laboratories, international inspection agents, and so on, the current scenario makes the Brazil out of the high level group of countries in terms of vehicle legislation and technology. The main countries in terms of motorcycle marketing already adopted ECE R41.04, such as European ones, or have national legislations that have R41.04 as base, like Asian countries.

This situation of different standards primarily creates a huge technical barrier analyzing the trends and needs of marketing, import and export. Models that are already developed and fulfilling EURO approval may not be accepted in Brazilian market, and vice versa, also creating an extra cost to engineering and development.

L-CATEGORY OVERVIEW

Besides the motorcycles (L3 category), there are the other L-Category vehicles, such as mopeds and tricycles that are all out of harmony and needs special attention in order to have the specific requirements correctly set.

The table below indicates the specific regulation for each type of vehicle.

Table 5. L-Category base regulation

Vehicle	Category	Base Regulation
Moped	**L1**	UNECE R63
3-wheeled Moped	**L2**	UNECE R9
Motorcycle	**L3**	UNECE R41
Motorcycle with side-car	**L4**	UNECE R41
Tricycle	**L5**	UNECE R9
Light Quadricycle	**L6**	UNECE R63/R9
Heavy Quadricycle	**L7**	UNECE R9

3. PRACTICAL TESTS

PURPOSE

The purpose of the practical test is to demonstrate that the new method, R41.04, has no impact in the emitted sound level when compared to the current standard. Each test result was analyzed with the respective sound level legislated limit, and their margins.

In order to understand the relation between the two methods, ECE R41.04 and ABNT NBR 15145, a practical study was carried out with some motorcycles, as shown below:

-Quantity: 11 (different models);

-Brand: 10 YAMAHA units, 1 model of another brand;

-Program: All PROMOT M4 homologated units;

-PMR: Variation of small motorcycles (PMR 40) until big motorcycles (PMR 300);

-Classes*: 4 units of Class II

7 units of Class III

*There are no representative models for Class I.

METHOD

The same unit of each model performed measurements according to ABNT NBR 15145 with full throttle acceleration, and posteriorly performed measurements according to ECE R41.04, making runs with full throttle acceleration and at constant speed, the final considered result is the L_{urb}.

RESULTS

The obtained results, in orange, were plotted in the dispersion graphs. To have a comparison, results of the WP.29 working group at the time of R41.04 development are plotted below:

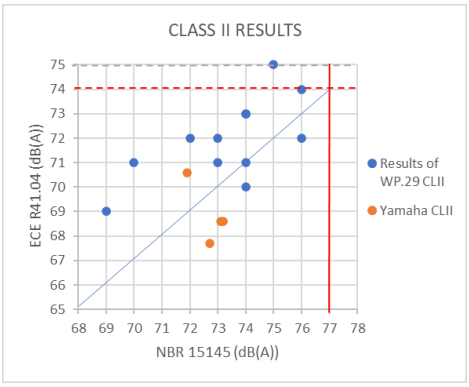

Figure 10. Noise results graphs – Class II.

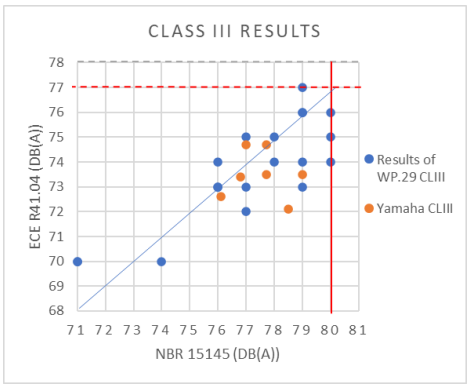

Figure 11. Noise results graphs – Class III.

The results demonstrated that the margin limits, in the majority, are close when we compare the difference of the measured result of ECE R41.04 and its limit, and the measured result of ABNT NBR 15145 and its limit.

It is also possible to analyze that the results measured in the current motorcycles are similar to the study for R41.04 development, demonstrating basically the same variation with the limits.

The table below shows the individual results and the differences mentioned.

Table 5. Test results

Class	NBR	NBR limit	NBR limit dif	NBR limit dif	ECE L_{urb}	ECE limit	ECE limit dif	ECE limit dif	dif NBR ECE	dif NBR ECE
-	dB(A)	dB(A)	dB(A)	%	dB(A)	dB(A)	dB(A)	%	dB(A)	%
CLII	71,9	77	5,1	6,6%	70,6	74	3,4	4,6%	1,7	2,0%
CLII	73,1	77	3,9	5,1%	68,6	74	5,4	7,3%	-1,5	-2,2%
CLII	72,7	77	4,3	5,6%	67,7	74	6,3	8,5%	-2	-2,9%
CLII	73,2	77	3,8	4,9%	68,6	74	5,4	7,3%	-1,6	-2,4%
CLIII	76,1	80	3,9	4,9%	72,6	77	4,4	5,7%	-0,5	-0,8%
CLIII	77,7	80	2,3	2,9%	73,5	77	3,5	4,5%	-1,2	-1,7%
CLIII	79	80	1,0	1,3%	73,5	77	3,5	4,5%	-2,5	-3,3%
CLIII	77	80	3,0	3,8%	74,7	77	2,3	3,0%	0,7	0,8%
CLIII	78,5	80	1,5	1,9%	72,1	77	4,9	6,4%	-3,4	-4,5%
CLIII	77,7	80	2,3	2,9%	74,7	77	2,3	3,0%	0	-0,1%
CLIII	76,8	80	3,2	4,0%	73,4	77	3,6	4,7%	-0,4	-0,7%
Max	**79**	**80**	**5,1**	**6,6%**	**74,7**	**77**	**6,3**	**8,5%**	**1,7**	**2,0%**
Min	**71,9**	**77**	**1,0**	**1,3%**	**67,7**	**74**	**2,3**	**3,0%**	**-3,4**	**-4,5%**
Average	**75,79**	**78,91**	**3,12**	**4,0%**	**71,82**	**75,91**	**4,09**	**5,4%**	**-0,97**	**-1,4%**

The results obtained according to ABNT NBR 15145 demonstrated a margin with the limit of 3,12 dB (A), in average. In parallel, the results through ECE R41.04 were 4,09 dB(A).

This finally results in a general difference between two standards of less than 1,0 dB(A), considered a slight difference.

This evaluation attests that regardless of the test procedure evolution, the current standard sound level will be maintained. The adoption of the new methodology of ECE R41.04 does not cause environmental loss and may be studied over time after its adoption for constant evolution and improvement, making possible further reductions in limits.

ASEP PRACTICAL TESTS

To evaluate the ASEP (Additional Sound Emission Provisions), it was decided to perform some practical tests.

-Quantity: (2 different models);

-Brand: 2 YAMAHA models;

-Program: PROMOT M4 homologated units;

-PMR: Big motorcycles (PMR>200);

-Classes: 2 units of Class III

As the European standard R41.04 defines, the ASEP is currently required only for motorcycles with PMR above to 50.

Retaking the explanation in the introduction, the ASEP was developed to evaluate the conformity of the noise level in different conditions.

Just to remember, the regular requirement for this type of motorcycles is the full throttle acceleration running test in the vehicle speed of 50km/h, resulting in the wide-open-throttle test result (L_{wot}), which after the calculation and ponderation with the constant speed test

result (L_{crs}) must be in compliance with the regulated sound level limit.

For the ASEP test, the L_{wot} and n_{wot} must be determined by new measurements according to the regular procedure, in the same gear and same pre-acceleration conditions. With these results, considered as base results, the ASEP limit line is generated, according to the formulas below:

$$L_{wot,(i)} + (1 * (n_{PP'} - n_{wot,(i)}) / 1{,}000) + 3 \text{ for } n_{PP'} < n_{wot,(i)} \text{ and} \quad (6)$$

$$L_{wot,(i)} + (5 * (n_{PP'} - n_{wot,(i)}) / 1{,}000) + 3 \text{ for } n_{PP'} \geq n_{wot,(i)} \quad (7)$$

After the equation line, several runs might be made in lower or higher gears than the original tested gear. An extensive range of vehicle speed and engine speeds might also be tested, considering the restrictions of each vehicle.

The obtained results for the ASEP evaluation can be observed in the figures below:

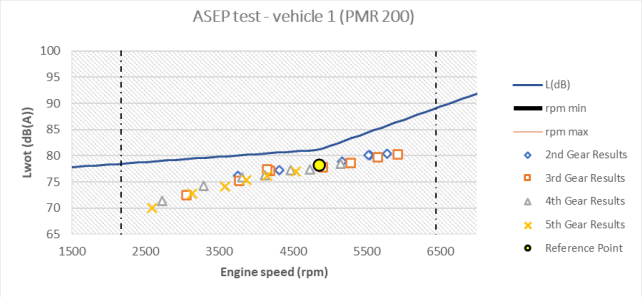

Figure 12. ASEP Noise results graphs – Vehicle 1.

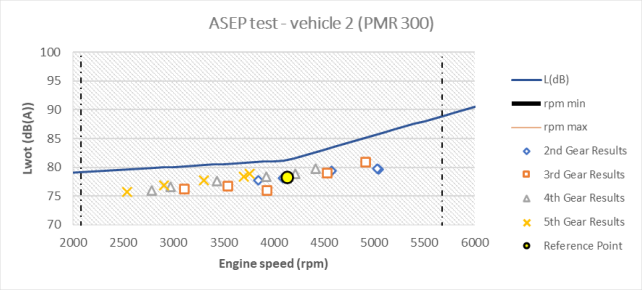

Figure 13. ASEP Noise results graphs – Vehicle 2.

As observed, although the tested models were primarily developed to comply with the current Brazilian environmental program PROMOT M4, in line with the ABNT NBR 15145 procedure, the results showed that the vehicles would comply with the ASEP methodology, demonstrating noise level below the limits in all the tested ranges.

The introduction of ASEP into Brazilian regulation, besides the harmonization with Europe, would reinforce the importance of noise level control in all ranges of speed and engine speed, not only in the regular procedure.

CONCLUSION

It is important to note that the 04 series of R41 was primarily based on the driving behavior of motorcycles, using no more data from other types of vehicles through an extensive study that was also used for the exhaust emission test procedure, the WMTC, internationally recognized and widely used.

Increasingly, the vehicle standards try to achieve real driving conditions, and R41.04 is no exception. With the use of partial acceleration replacing the full throttle method, is possible to better analyze the results obtained in the test and reflect to the real urban noise.

The obtained results in the practical test showed that the limits of ECE R41.04 were defined in such a way to not bring environmental loss comparing to the old ECE R41.03, which ABNT NBR 15145 was based on. Analyzing the difference between the measured noise result with the respective limit of each method, it is observed a difference of less than 1,0 dB(A) in average, which can be considered a slight difference thinking in the environment protection.

In addition, the ASEP method is a new manner to understand the noise behavior of some vehicle in other patterns different from the test demands, creating an expansive legal base data and making possible a wide study for a possible future review of the test procedure. It is important to note that the ASEP methodology is a new area for study for motorcycles and similar vehicles around the world, and specially for Brazilian industries and market, the study of technical procedures such as the ASEP has substantial factor for the globalization aimed to environment. With ASEP, would be possible to cover a wider spectrum of noise behavior, including improvements in the detection of the use of defeat devices, detection that nowadays is harder to take with the current standard only. Besides not harming, ASEP only expands more testing and compliance.

Regarding harmonization, there is a discontinuity of harmony between the Brazilian requirement and the European one, which can generate an enormous technological gap, as well as additional costs for specific development for Brazil.

The adoption of ECE R41.04 is the first step to the continuation of environmental protection. As this standard is worldwide used, the continuous improvement is always in discussion, differently from what happens with the current Brazilian method.

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