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PROCEDURE, MEASUREMENT CHAIN AND EXPERIMENTAL SET-UP FOR THE FUNCTIONAL PARAMETERS DETERMINATION OF AUTOMOTIVE ENGINES EXHAUST SILENCER VEHICLES

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Abstract— The paper presents the procedure and the experimental set-up for some functional parameters determination as the noise level, the pressure drop and the temperatures through investigating three different manufacturing solutions for mufflers. An algorithm and a dedicated method have been proposed in order to emphasize more direct the mufflers influence on the engines performances. The procedure equally includes particular cycles of the engine and it is highlighted the relation between the engine operating conditions and the functional parameters of the automotive mufflers. The experimental results emphasize the corroboration between these parameters and contribute to the improvement of the muffler fabrication and design since it is a complex function that affects noise characteristics, emission and fuel efficiency of engine. It was designed a measurement chain for the noise level evaluation of the mufflers. It was also created a measurement chain for the pressure – drop evaluation and temperature distribution on the external surface of the mufflers.

Keywords— mufflers, silencer, noise level, sound pressure, pressure-drop, third-octave analysis, temperature measurement, temperature distribution, thermographic images.

I. INTRODUCTION

THE most important component of the noise from the internal combustion engine of the vehicle appears on the exhaust system. It is generated by removal of flue gas speeds and their pulsatile pressure during the evacuation process.

Since the exhaust noise depends on a great number of factors such as the engine cylinders number, the engine capacity, the gas distribution phases, the construction of the exhaust system, the uniformity and the engine working sequences, it is difficult to make a rigorous calculation [1]- [4].

As is known, the noise reduction is mainly by fitting silencers, also called mufflers. The role of the absorption attenuator is to reduce noise components of mid and high frequencies, in this case the first harmonic being the most significant [5]- [10].

The accurate data are only achieved by the experimental tests. However, the analytical calculations can be useful in the optimization of the mufflers constructive solutions [7].

There are numerous functional requirements that should be considered when designing an automotive muffler such as the exhaust gas flow, the influences of gasodynamic resistance on the engine performances, adequate insertion loss, the spectral component of noise, backpressure, pressure drop, durability, size, mass, cost, shape and style [8].

This paper deals with a practical experimental approach for the determination of some principal functional parameters as the noise level, the pressure – drop and the exterior surfaces temperatures. The experimental results, obtained by the authors emphasize the corroboration between these parameters and contribute to the improvement of the muffler fabrication and design thereby reducing noise level, emissions and fuel consumption of the engine.

II. PROCEDURES

The noise measurements must be in accordance with a methodology established by the international standards, in order to compare the results obtained for different mufflers. The imposed conditions relate to the sound field, the microphones path, the measuring equipment, the engine installation and operation and also the criteria for noise analysis are taken into account [1].

A sound measurement scheme – *A-weighting* – is usually used to filter microphone sound pressure readings to reflect human sensitivity, and give overall sound pressure readings, in decibels (dB(A)) [9].

We use an *RMS* (*R*oot *M*ean *S*quare) value of the pressure fluctuations to obtain a logarithmic measure, expressed as *Leq*. The sound energy may manifest itself in a wide range of frequencies, frequencies audible to the human ear is from about 20 (Hz) to 20 (kHz). According to the sound measurement procedure, an *octave band* convention was chosen. Successively, the bandwidth of the progressive band is considered the double of the previous band. Central frequencies allocated to the full range of audible bands are: 31.5, 63, 125, 250, 500, 1000, 2000, 4000 and 8000 [2].

The microphone is located at the end of the exhaust duct at a distance of 0.5 (m) from the exhaust pipe and at an angle of 45° to the flow axis of the pipe termination [11].

The noise analysis consists in a third-octave analysis realized at various engine speeds and it is also measured the overall exhaust sound level [5].

The parameters analysis and the behavior of constructive variants of mufflers, impose the adoption of some particular measurement methods according to some general requirements of the European standards [12].

The engine running under specific loads and speeds was simulated using a chassis dynamometer.

The particular operating conditions imposed some deviations from the regimes recommended by the standards. The determinations were realized at 0%, 50%, 90% load and engine speeds of 1500 and 1800 (rpm). Three sets of determinations for these operating regimes have been performed, in order to eliminate the accidental errors.

III. INSTRUMENTATION OF THE TEST BED AND EXPERIMENTAL SET-UP

To carry out the tests included in the experimental procedure, a diesel engine which equipped a passenger car was used (Fig. 1).

Fig. 1. Experimental set-up

The tests were performed on the *LPS 3000 MAHA* chassis dynamometer (Fig. 2).


Fig. 2. The *LPS 3000 MAHA* chassis dynamometer

The measurement chain of noise parameters consists of:

1) *a Bruel&Kjaer microphone of type 4133 (sensitivity 4-16 (mV) la (N/m^2); 0.4-1.6 (mV) per (µbar); 36 - 150 ((dB) (A));*
2) *a Bruel&Kjaer precision sound level analyzer type 2209 (amplification: 2 (Hz) or 10 (Hz) at 70 (kHz); standard filters according IEC R179, IEC R179A şi ANSI Type 1) connected with the microphone and NI DAQ;*
3) *a multifunctional external data acquisition board type-NI DAQPad-6015 on USB;*
4) *a laptop Acer with LabVIEW soft compatible with National Instruments DAQPad for data processing.*
5) *The noise level (dB(A)), A weighted, was measured using two adapted LabVIEW tools:*
6) *Third-octave analysis - measuring total band power and the noise level in the frequency bands (dB);*
7) *Sound level meter - measuring Leq (A) - equivalent continuous sound pressure level (dB).*

Specifications for these tools included in *LabVIEW* library are defined by *ANSI* and *International Electrotechnical Commission (IEC)* standards and the results are fully compliant to the international standards (ANSI S1.11-2004 and the IEC 1260:1995 standards).

To measure the temperature on the external surface of the mufflers an infrared camera (*Flir ThermaCAM E300* model) was used with the following technical specifications: image resolution 320 x 240 pixels; temperature range -20,...,500(ºC); accuracy ± 2(°C) or ± 2 % of reading; communications interfaces - RS-232, USB 2.0, video output.

For different operating regimes, the pressure drop on mufflers was measured with a glass *U-tube* manometer with mercury. An additional glass *U-tube* manometer was used to measure backpressure.

Fig. 3. Instrumentation for temperature measurements

IV. Particular Measuring Cycle of the Engine

In order to obtain the relevant results (noise level, pressure drop and temperatures) of each operating regime of the engine, the tests were carried out in accordance with a measuring cycle designed in this experiment (Fig. 4). This cycle includes idle running breaks interposed between engine operating stages in load regime. These breaks were included in the measuring cycle to ensure the same thermal state before each temperature measurement. For example, in Fig. 5, a load simulation diagram recorded on chassis dynamometer is presented.

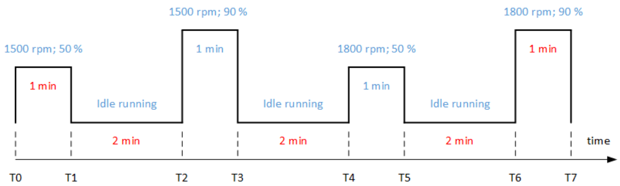


Fig. 4. Measuring cycle of the engine

With the operating mode *Constant Engine RPM* the chassis dynamometer is regulated in such a way that the engine RPM remains constant independently from the traction and speed created by the vehicle. The pre-selected target value (n-target) is regulated independently from the traction created by the vehicle up to the maximum chassis dynamometer motor capacity.

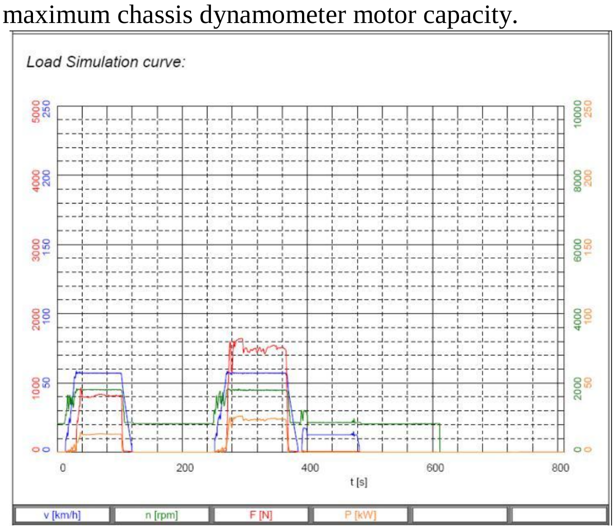
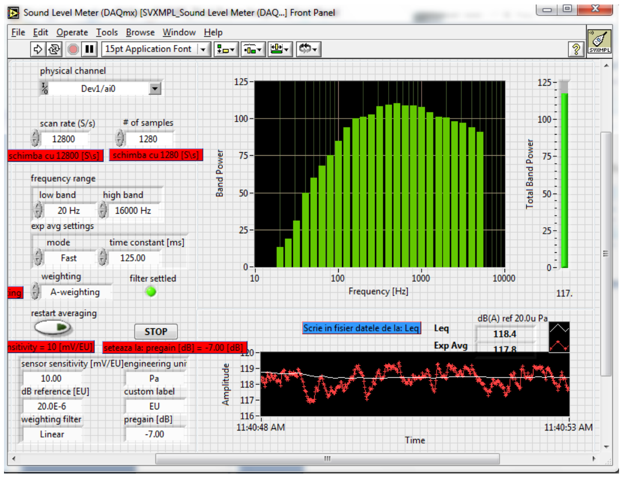


Fig. 5. Cycle load simulation diagram

V. Tests and Results

In this paper, for the three manufacturing mufflers solutions, we were used the identification with numbers: muffler *0*, muffler *1* and muffler *2*.

Some relevant experimental results of the tests at load 90% load, 1500 (rpm) for the muffler *1* are presented in Fig. 6.



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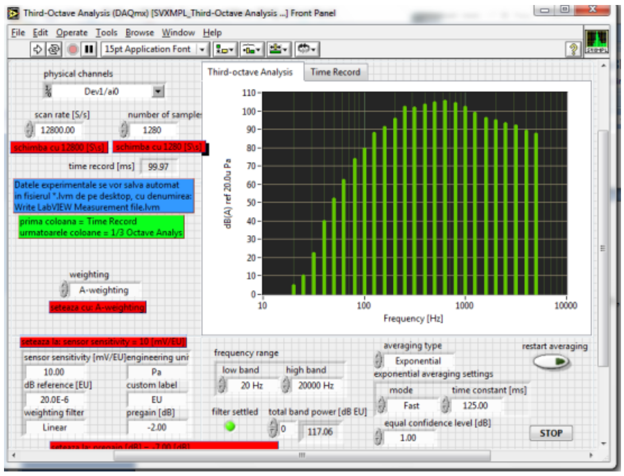


(b)

Fig. 6. Third-octave analysis and Sound level meter muffler *1*, load 90%, 1500 rpm.

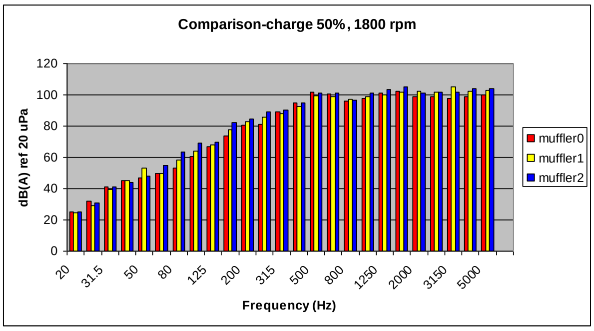


Fig. 7. *Third octave* comparison - load 50%, 1800 rpm

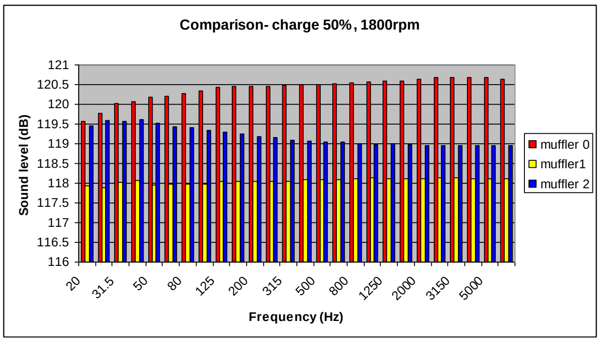


Fig. 8. *Sound level* comparison - load 50%, 1800 rpm

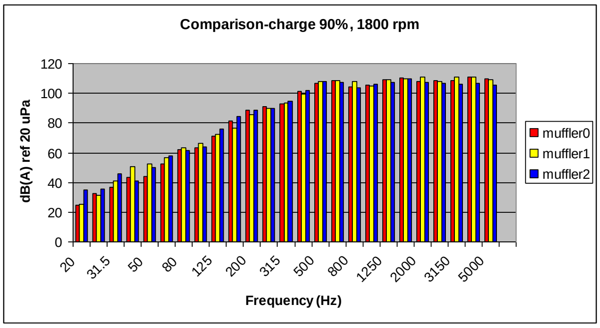


Fig. 9. *Third octave* comparison - load 90%, 1800 rpm

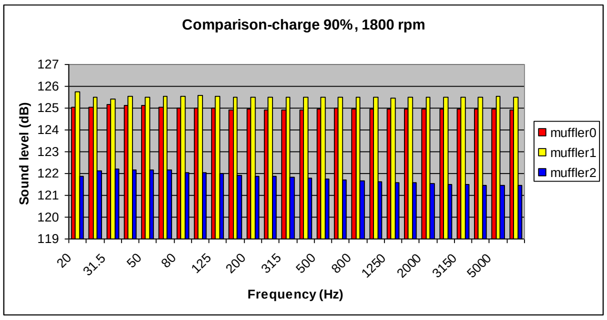
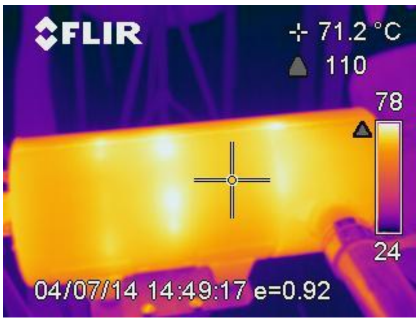


Fig. 10. *Sound level* comparison - load 90%, 1800 rpm.

The comparative analysis of the experimental results related to the noise level for the three manufacturing mufflers solutions can be easily performed on the basis of the following graphs, presented in Fig. 7, Fig. 8, Fig. 9 and Fig. 10.

To carry out a more complete analysis of the thermal behavior of the mufflers, the temperature distribution and also the high temperature areas on the entire exterior surface have been emphasized by thermographic images, presented in Fig. 11.



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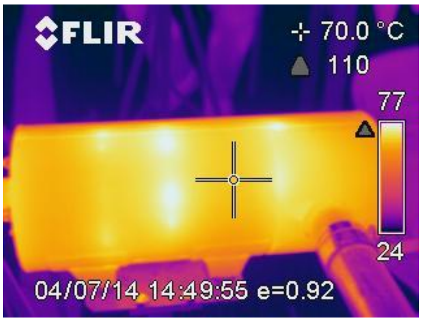

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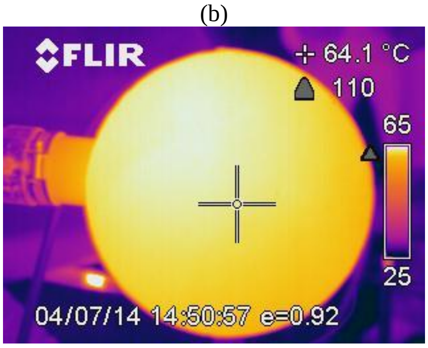

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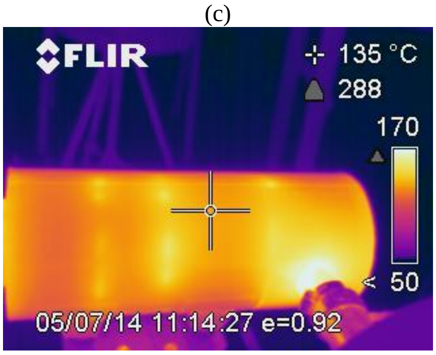

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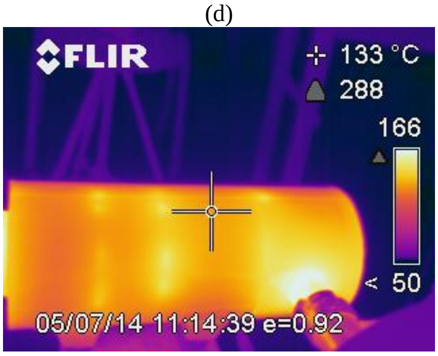

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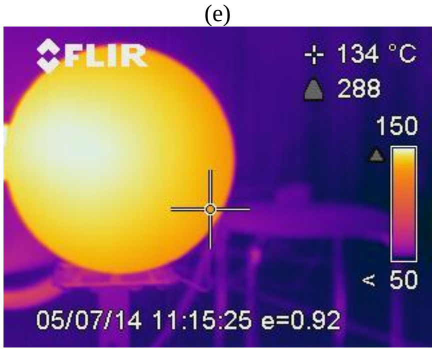

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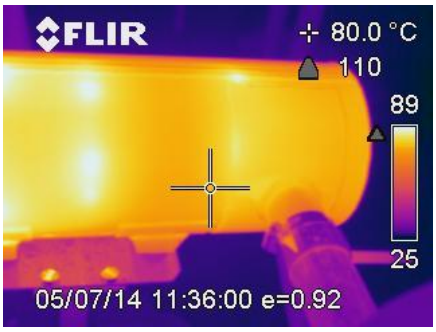

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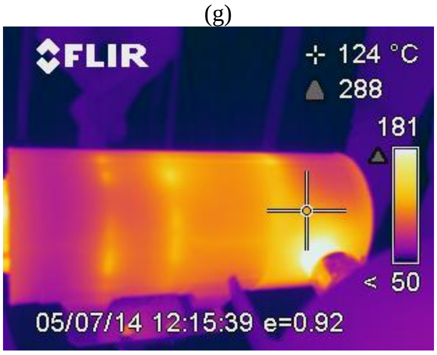

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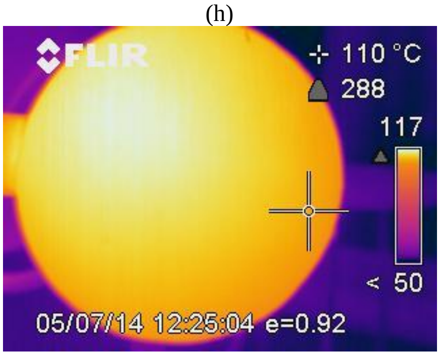


(i)

Fig. 11. Thermographic images with temperature distribution and high temperature areas on the exterior muffler surface

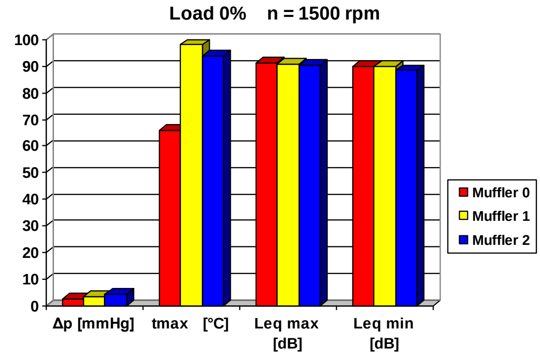
The experimental final results are synthetically presented as graphs in figure Fig. 12, Fig. 13, and Fig. 14 ordered based on the load of the engine (0 %, 50 %, 90 %), where:

1) *-Δp is the pressure – drop in (mmHg);*
2) *-t_{max} is the maximum temperature measured on the external surface in (°C);*
3) *-Leq is the equivalent sound pressure level.*

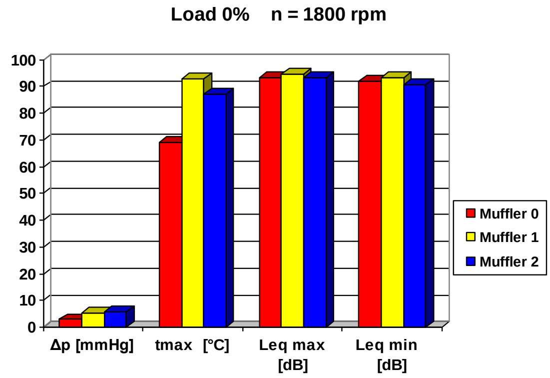
Concerning the temperature, for mufflers *1* and *2* the maximum temperature measured on the external surface is relatively close to the reference silencer *0*, for engine load 50% and 90%.

When the engine load raises, the temperature differences decrease to a maximum of 17% for silencer *1* and to 6.25% for silencer *2* (90% load at 1500 (rpm)). For an engine load of 90% at 1800 (rpm), the external temperature for silencer *1* and silencer *2* are lower than silencer *0*.

As a consequence, of temperatures measurement, the silencers *1* and *2* demonstrate the phenomenon of a bigger thermal inertia compared to silencer *0*. This phenomenon is present in the process of heating also in the process of cooling the silencers. In the graphs it can be seen that the noise level for all the three manufacturing solutions silencers are at almost the same level. In all cases the noise level was lower for silencers *1* and *2* with 1.52% at 0% load to 7.61% at 90% load.

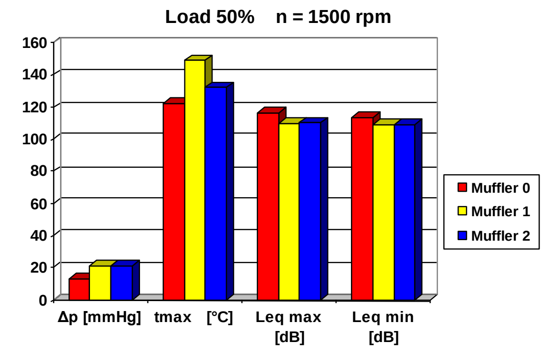


(a)

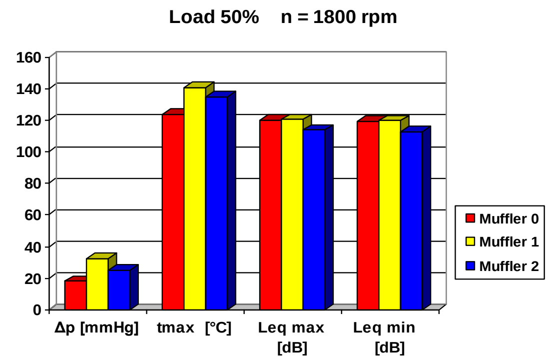


(b)

Fig. 12. Synthetic results - Load 0 %

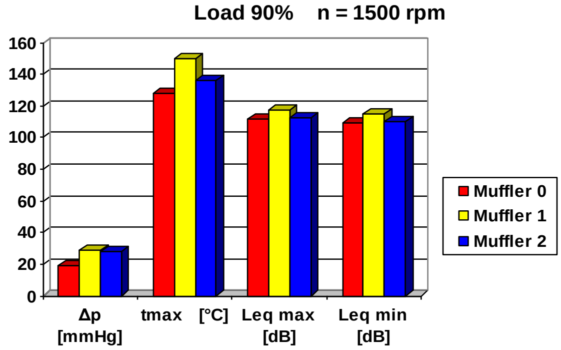


(a)

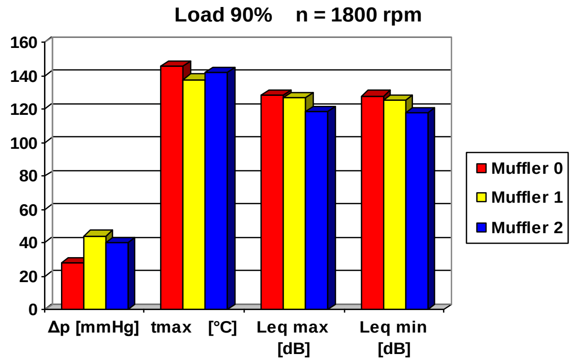


(b)

Fig.13. Synthetic results - Load 50 %



(a)



(b)

Fig. 14. Synthetic results - Load 90 %

The effect of noise attenuation for silencers *1* and *2* is accompanied by an increase in drop-pressure between in and out of the silencers.

VI. Conclusions

1) *An algorithm and a dedicated method have been proposed in order to emphasize more direct the mufflers influence on the engines performances.*
2) *The procedure includes particular cycles of the engine and the relation between the engine operating conditions and the functional parameters of the automotive mufflers are highlighted.*
3) *The measuring cycle which has been proposed and described in this paper could provide the noise, temperature and pressure determinations, within the particular imposed functioning conditions.*
4) *At the same time, the noise measurements were in accordance with a methodology established by the international standards in order to compare the results obtained for different mufflers.*
5) *The conducting of experimental protocol by measuring chain proved to be easy and friendly, being a good basis for continuing these kinds of experiments.*
6) *As a final conclusion, the performance of three solutions mufflers is very close in terms of noise levels and maximum temperatures on the outer surface. In charging regimes reveals a slight increase in the difference between the pressure drops of the three variants. This suggests that, if major structural changes are made for the mufflers, there is a risk that for the same level of noise, the energy and the economic performance of the engine can be damaged.*

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