the levels of sound pressure in a determined position exposed to the noise, before and after the installation of the cover, with the same settings for the noise source and the same atmospheric conditions. This parameter is, then, expressed with the relation:

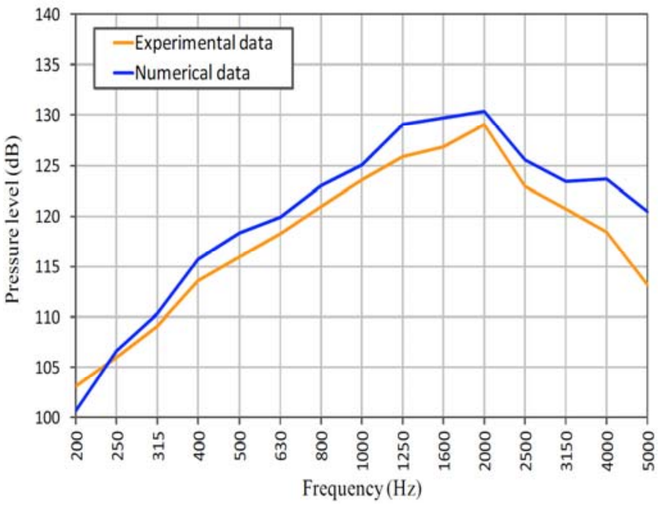

Fig. (18). Pressure level - Microphone C.

$$IL = L_{pX,(ante-operam)} - L_{pX,(post-operam)} \quad [dB] \tag{2}$$

where, $L_{px(ante-operam)}$ indicates the sound pressure level before the insertion, while $L_{px(post-operam)}$ indicates the sound pressure level after the insertion of the shielding component.

In regard to the calculation of the *Insertion Loss*, the position of microphone A (1 m over the cover) was chosen as monitoring point for the noise attenuation. Consequently, the sound pressure level in that point was considered, with and without the cover. Moreover, it was deemed appropriate to report the corresponding diagrams in third of octave bands. The estimation of the *Insertion Loss* takes into account both the experimental data, obtained in semi-anechoic chamber, and the numerical data; the obtained diagrams were, then, compared in order to determine their degree of correlation.

The estimation of the *Numerical Insertion Loss* was carried out considering the numerically obtained data, therefore, the sound pressure level in A (1 m over the cover) was evaluated with and without the cover and then the above formula (2) was applied (Fig. **19**).

The *Experimental Insertion Loss* was evaluated by taking into account the experimental data obtained in a semi-anechoic chamber; through these data the sound pressure level in A (1 m over the cover) can be determined, with and without the cover, and then the formula (2) of the *Insertion Loss* reported above was applied (Fig. **20**).

Once extracted, the numerical and experimental diagrams, related to the *Insertion Loss*, were compared in order to determine their correlation degree (Fig. **21**).

This comparison showed a satisfactory degree of correlation in all the analysed range of frequencies and, in particular, revealed to be optimum in the interval 2-5 kHz, interval of considerable importance in the automotive field.

6. CONCLUSIONS

Given the level of generality of the tested procedure, the model can be applied to any structural element of the same typology (not only of automotive type), with the aim to numerically determine its effectiveness in noise attenuation.

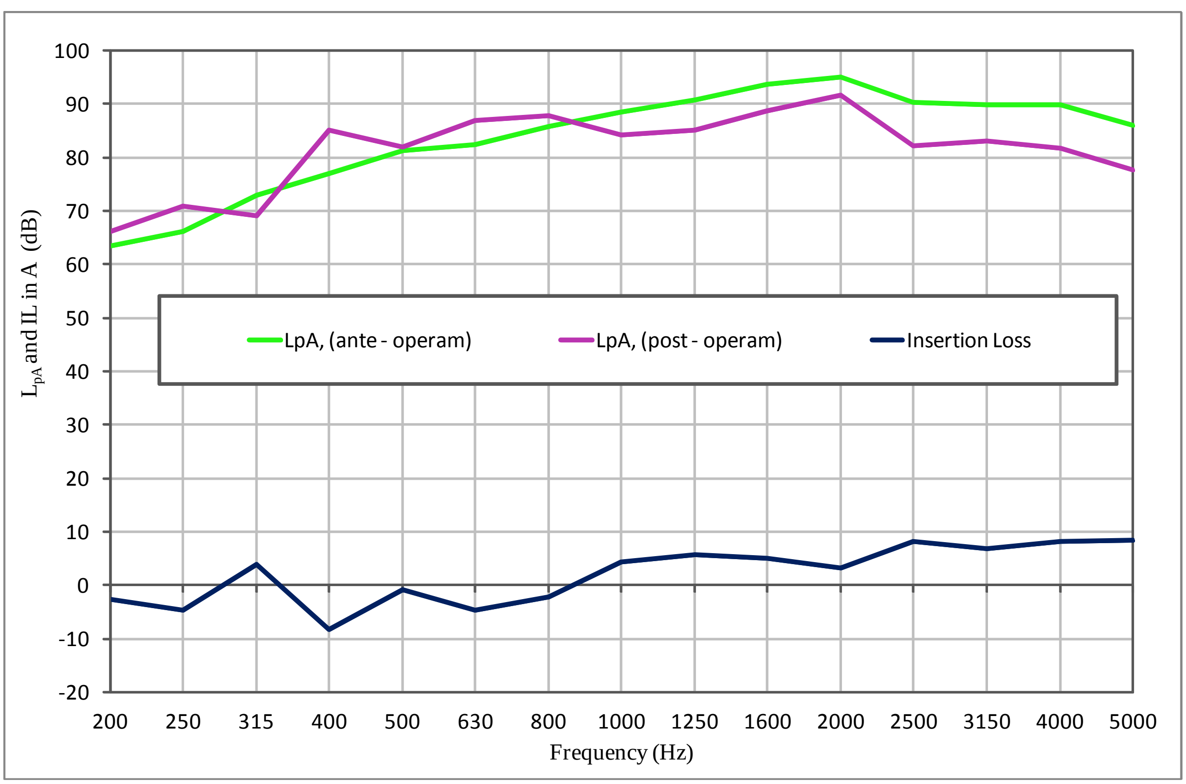

Fig. (19). Sound pressure levels in *A* (1 m over the cover) and *Insertion Loss* (numerical data).

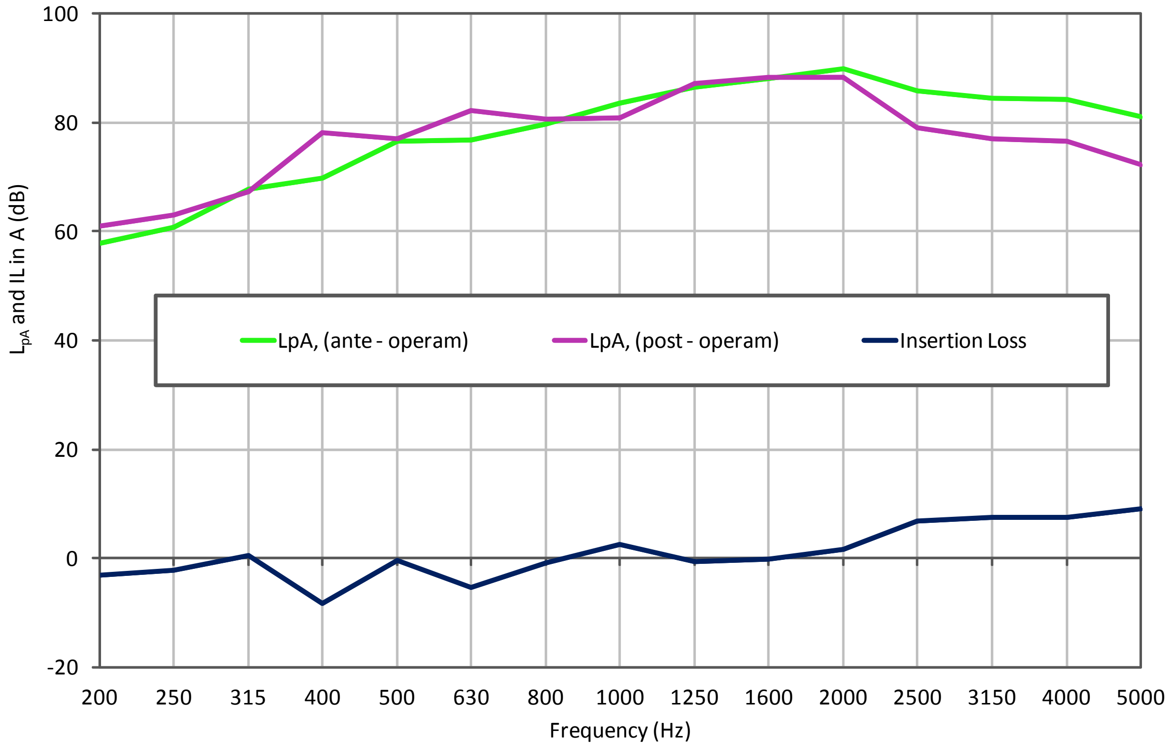

Fig. (20). Sound pressure levels in *A* (1 m over the cover) and *Insertion Loss* (experimental data).

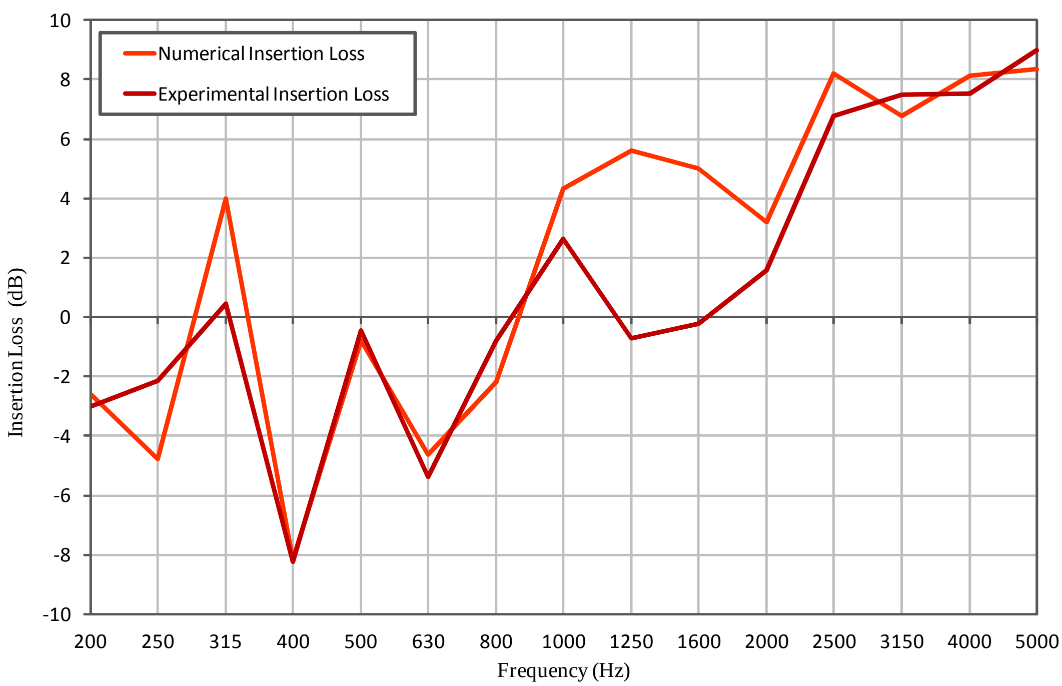

Fig. (21). Comparison between *Insertion Loss* in *A* (1 m over the cover).

Among the numerous advantages that the BE technology can offer in the acoustic field, are:

- a reduced discretisation effort;
- the possibility to easily evaluate the external problems in infinite domains;
- the possibility to easily characterise the surface acoustic behaviour by means of appropriate impedance values as boundary conditions;

and those offered by the an integrated FEM-BEM approach, like:

- high flexibility;
- a potentially higher possibility of improving the numerical-experimental correlation (BEM is potentially more accurate than FEM).

In consequence of the aforementioned peculiarities it is possible to consider the FEM-BEM approach a valid alternative to the traditional FEM-FEM (both dynamic and acoustic analyses made by FEM) approach.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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REFERENCES

[1] R. Citarella, and D. Siano, "Transmission loss assessment of an air induction system by BEM", In: *ICAD2006, The Fourth International Conference on Axiomatic Design*, Firenze, Italy, June 2006, pp. 13-16.

[2] D. Siano, and E.F. Corcione, "FE fluid-structure interaction/ experimental transmission loss factor comparison of an exhaust system", In: *7th International Conference on Engines for Automobile - ICE2005*, 2005.

[3] D. Siano, "Three-dimensional/one-dimensional numerical correlation study of a three-pass perforated tube", *Simulation Modelling Practice and Theory*, vol. 19, no. 4, pp. 1143-1153, 2011.

[4] R. Citarella, and M. Landi, "Acoustic analysis of an exhaust manifold by Indirect Boundary Element Method", *The Open Mechanical Engineering Journal*, vol. 5, pp. 138-151, 2011.

[5] R. Citarella, L. Federico, and A. Cicatiello, "Modal acoustic transfer vector approach in a FEM-BEM vibro-acoustic analysis, *Engineering Analysis with Boundary Elements*, vol. 31, pp. 248-258. 2007.

[6] R. Citarella, P. Colantuono, and D. Siano, "Vibration prediction of a multi-cylinder engine using multi-body dynamic simulation", In: *41° National Conference AIAS 2012*, Vicenza: Italy, September 5-8, 2012.

[7] D. Siano, "Engine Noise Prediction by Using Multi-body Simulation", *Journal of Environmental Science and Engineering B 1*, pp. 1146-1161, 2012.

[8] D. Siano, and S. Giacobbe, "Radiated engine noise prediction using multi-body simulation", In: *EURODYN2011, 8th International Conference on Structural Dynamics*, Leuven: Belgium, 2011.

[9] LMS Virtual Lab, User's Guide.

[10] V. Mallardo, M.H. Aliabadi, A. Brancati, and V. Marant, "An accelerated BEM for simulation of noise control in the aircraft cabin", *Aerospace Science and Technology*, vol. 23, pp. 418-428, 2012.

[11] A. Brancati, M.H. Aliabadi, and V. Mallardo, "A BEM sensitivity formulation for three-dimensional active noise control", *International Journal for Numerical Methods in Engineering*, vol. 90, pp. 1183-1206, 2012.

[12] O. von Estorff, J.P. Coyette, and J.L. Migeot, Governing formulations of the BEM in acoustics", In: *Boundary Elements in Acoustics - Advances and Applications*, O. von Estorff, Ed., WIT Press: Southampton, 2000.

[13] M.A. Hamdi, "A variational formulation by integral equations for the solution of the Helmholtz equation with mixed boundary conditions" (in French), *Compte-rendus Académie des Sciences*, vol. 292, 1981.

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