Statistical – Inverse Boundary Element Method

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Abstract

This paper will introduce a novel technique to compute noise radiation from large structures (e.g. factories, steel civil structures etc.). The method is based on the Boundary Element Method, but it makes use of a statistical algorithm and some simple, hypothetical vibration forms to compute *farfield* noise radiation. Gross simplifications are introduced in the BE model to makes possible to perform BEM computations at all (the real model size of a large building for example would be too large for even the best computers of our days). All these simplifications and assumptions lead to the development of a computed, non-real sound field, which however approximates the real sound field in the farfield adequately. After having described the method, its potential will be demonstrated by two industrial examples.

1 Introduction

Noise radiation of large structures (e.g. factories, steel civil structures etc.) is very difficult to describe, in order to determine the predominant partial noise sources. Because of the complexity and the large dimensions of such structures, various partial noise sources contribute to the resulting overall noise emission into surrounding critical points differently. In order to be able to perform successful and effective noise reduction, the contribution of the sources has to be determined and to do this, usually the whole structure's noise radiation should be modelled. Two problems have to be overcome: the determination of surface velocity of the structure – at least for the noise radiating parts of the structure, and to produce a numerical model which can be handled of our computers.

This paper will introduce a novel Boundary Element Method based solution for such problems. It uses 2D models and a statistical algorithm to determine the noise contributions of different parts of the structure. Due to the BEM kernel of the method, it can give accurate results in well-determined observation points around the structure. After having described the method, its potential will be demonstrated by two industrial examples.

2 Problem description

Noise radiation of complex sources can be very well studied by means of the Boundary Element Method. The process begins by preparing a discrete model of the boundaries of the noise source and another set of discrete measurement points. Based on the geometry, Acoustic Transfer Matrices (ATMs) [1], relating the surface vibration of the source elements to the measurement points, can be computed for various frequencies. As a next step, by using direct surface velocity measurements or by computing them using some kind of inverse methods (e.g. Inverse Boundary Element Method [2,3]) the noise radiation of the source can be computed anywhere around the source. This method works very well on small objects, but not on large structures, since the model size exceeds the capabilities of even the most powerful computers (for example: the BE model of a 70x14 m wall, which can be used until 1000 Hz consists of about 400.000 elements and nodes). On the other hand, the surface velocity points to be measured directly or the hologram points in front of them are too numerous. It would in principle also be possible to compute them by means of a structural FEM computation, but in most practical cases the excitation is just too complex or cannot be measured, therefore FEM is not a viable solution. As a consequence, exact velocity distribution is very often not available for BE calculations.

3 Statistical approach

The lack of information on the exact source velocity distribution would not be a problem in itself, since generally the noise control designer only needs to know, which *part* of the structure radiates most of the noise. This leads to the idea to divide the structure on larger parts and to make some gross assumptions on their behaviour (modal vibration, plate vibration, random vibration of small elements etc.). The vibration of each part is characterised by a single amplitude value and the vibration pattern, the phase of each part is determined randomly. This approach can be interpreted as substitution of the real noise by a set of uncorrelated noise radiators, each of them described by a simplified but well known velocity distribution. By using this simplification one can no longer expect exact sound field solutions in the nearfield of the structure, where mutual interactions between various parts of the source and the sound field play an important role. In the farfield as from a certain distance from the source, however, a simple energy summation of the noise radiated from individual parts of the source will probably lead to satisfactory accuracy. To release the solution from individual phase distributions, a large number of randomly selected phase distributions are used to compute the noise level in various observation points, and the results are square-averaged. To avoid interference phenomena the whole averaging process is performed on multiple frequencies, which are again averaged within third-octave bands.

As the method uses ATMs originating from BEM computations, the method is called Statistical Boundary Element Method (Figure 1). For example, we have to compute the noise level between 100 and 1000 Hz. In each of the 11 third-octave band we determine e.g. 9 frequencies, so we have to compute 11×9 = 99 ATMs. Using the ATM of a single frequency line we compute e.g. 100 solutions with different phase distributions. These 100 solutions together with the other 800 in the same third-octave band give square-averaged the noise level of a 1/3 band.

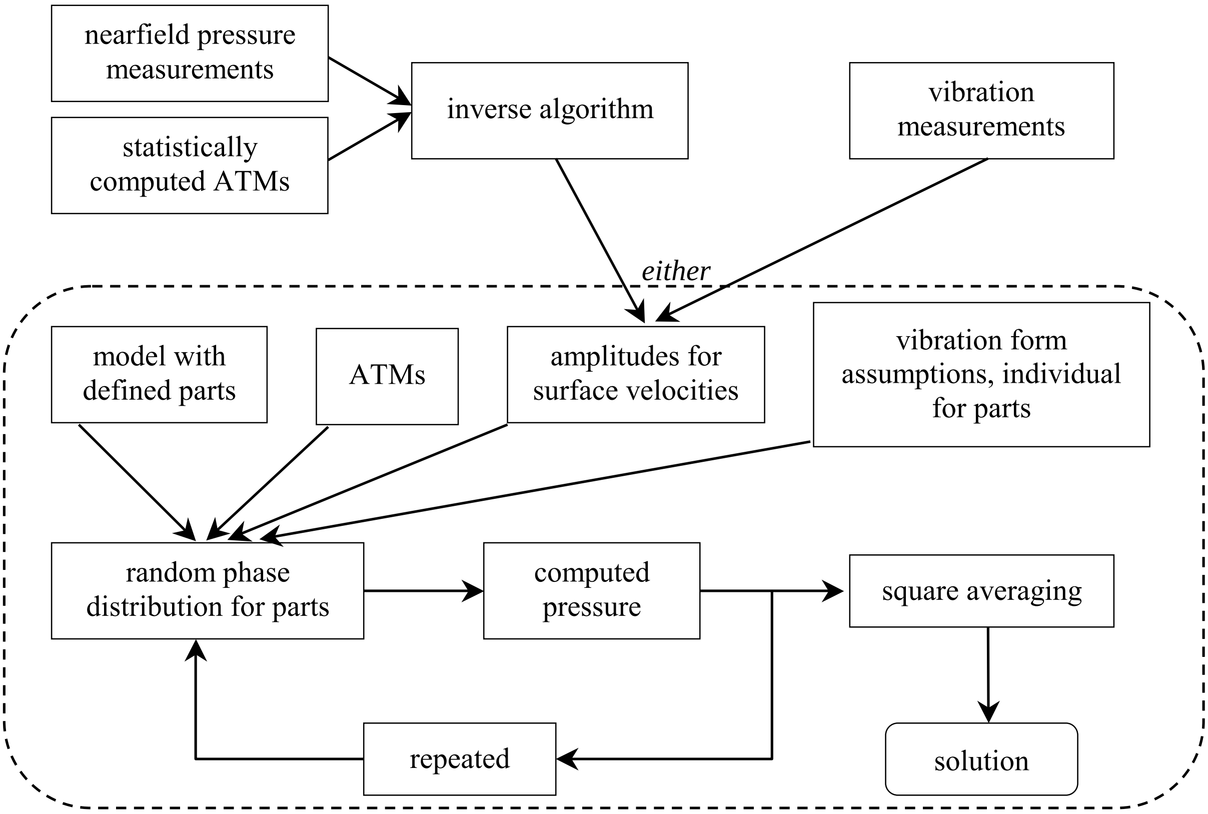


Figure 1: Combined Statistical-Inverse Boundary Element Method flowchart (the interrupted line borders the statistical part of the computation)

4 Advantages of the new method

The method described above uses an averaged, hypothetical noise propagation to compute farfield noise levels. It solves the problem of unacceptable large number of measurement points, but doesn't simplify the complexity of the BE model. To overcome this, 2D models (sometimes with gross simplifications) can be used because large, long structures are similar to infinitely long models, and detailed surface changes would anyway be averaged out. This way for example if the height of a building changes along the dimension, which will be taken as infinite, then an averaged height can be used.

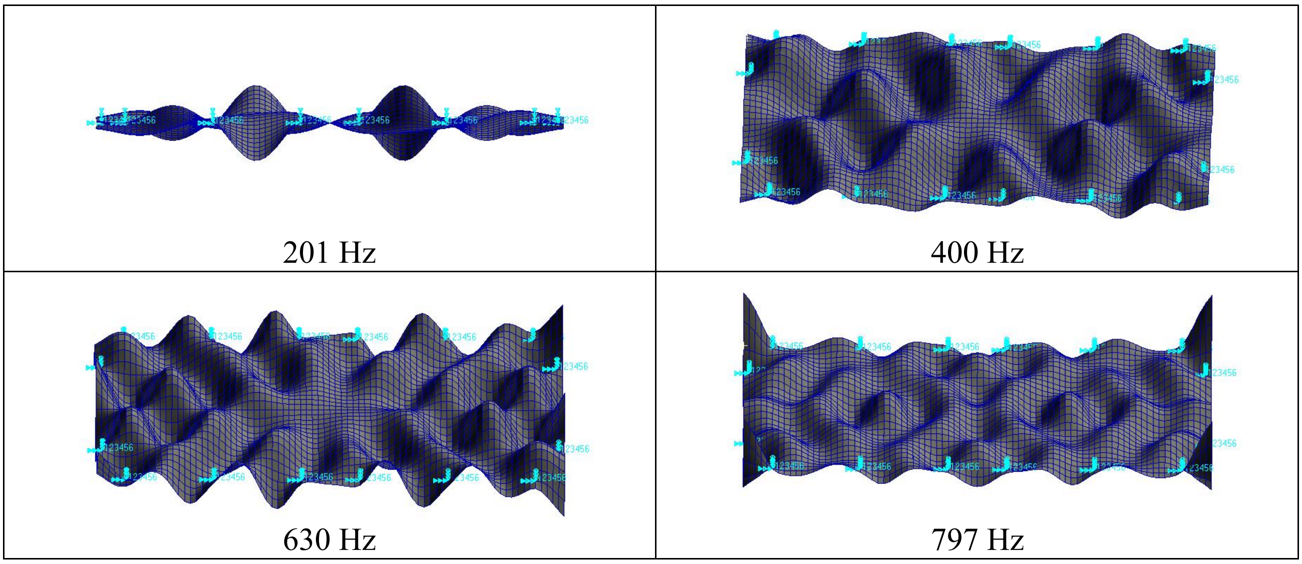
Another advantage lies in the small number of parts: if we cannot measure surface vibrations directly for any reason, we can perform nearfield pressure measurements and compute the surface velocity. Because of the small number of unknowns, the inverse computation will not be suffering from ill-conditioned matrices as in the case of a usual inverse BEM computation, therefore the critical determination process of the regularisation method/parameters can be dropped. Two-three microphones are enough to determine the surface velocity of a selected part if the vibration form of the surface is relatively well presumed.

Keeping in mind the main goal, i.e. determination of partial noise source contribution, the real potential of the method lies in the statistically created transfer functions. The global ATM of the structure can be split into smaller ones, each belonging to one single part of the structure only. Computing the noise level in an observation point based only on one single part's ATM, the total noise level can be decomposed into components originating from the building's individual parts. With this information the probable extent of noise level reduction can be estimated after vibration reduction of some parts of the building.

5 Examples

South Rail-way Bridge in Budapest (Figure 2): the steel structure is 470 m long, it raises the environmental noise level about 10 dBA in the course of train pass-bys. The structure is excited with a vibration from the interaction of the rail and the wheels, the dominant noise radiating components are the longitudinal main beams and the steel walking plates. In the pre-vibration control phase of the works detailed vibration measurements and farfield pressure measurement have been performed.

Figure 2: South rail-way bridge in Budapest above the Danube



201 Hz

400 Hz

630 Hz

797 Hz

Figure 3: Vibration forms of the steel walking plates

As the main surfaces consisted of large steel plates the behaviour of them was assumed to be modal. The whole structure was too large for a complete FEM analysis, but parts of the bridge could be modelled. The results of the analysis showed clear modal vibrations (with nodes from 3-7) on both plates (main beam and walking plate) (See Figure 3). As the BE model of the bridge was 2 dimensional, the selection of mode number wasn’t obvious, we let the statistical algorithm compute several results: using modes with 1-9 nodes.

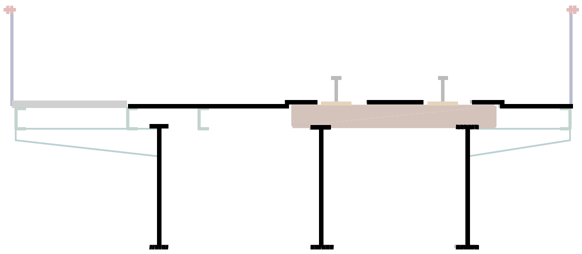


Figure 4: 2D model of the bridge *(only the black components were included)*

The 2D BE model was extremely simplified and consisted only of the sound radiating capable surfaces (see Figure 4). Surface velocities were given from measurements; the only freely selectable parameter was the mode number (given with half-waves per component). Using Statistical BEM, we computed the noise level between 100-800 Hz, and compared the results in a farfield point 19 m away from the bridge. As a first step, for the whole frequency range specified above, one mode was selected for the mean beams and independently, another one for the walking plates. The results are in an acceptable tolerance (Best approximations on Figure 5). The curves belong to modes with “mb” half-waves on the mean beam, and “wp” half-waves on the walking plates. As a second step, we created a more realistic excitation: the walking plates vibrated under 160 Hz in a mode with 2 half-waves, above 160 Hz with 3 half-waves. The vibration of the mean beam was fixed to 6 half-waves. On Figure 6 we see that this solution is very good, despite the fact that the excitation is only a fictive one, it is not the really physical vibration form of the plate. This form, however, is similar to the real one in the sense that it produces accurate results in the farfield. (The acoustical conditions in the nearfield are considerably complex: they are very sensitive to smooth changes on the surface velocity distribution).

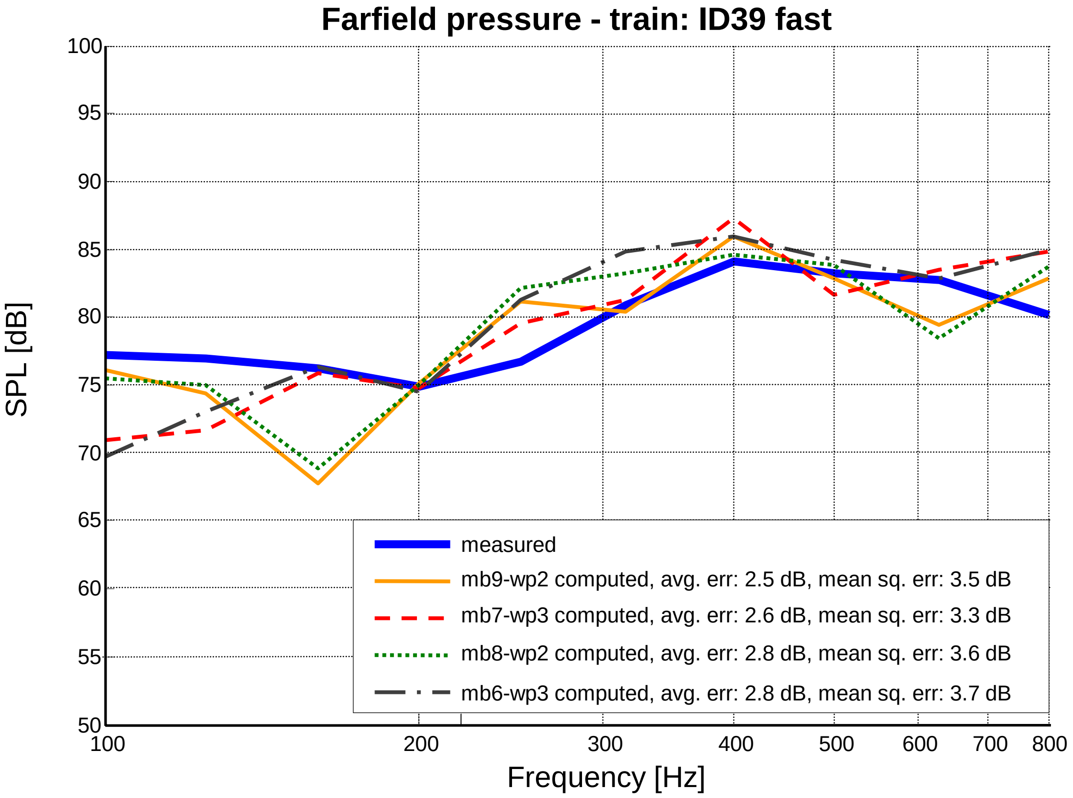


Figure 5: Best approximations of the sound pressure in the farfield point

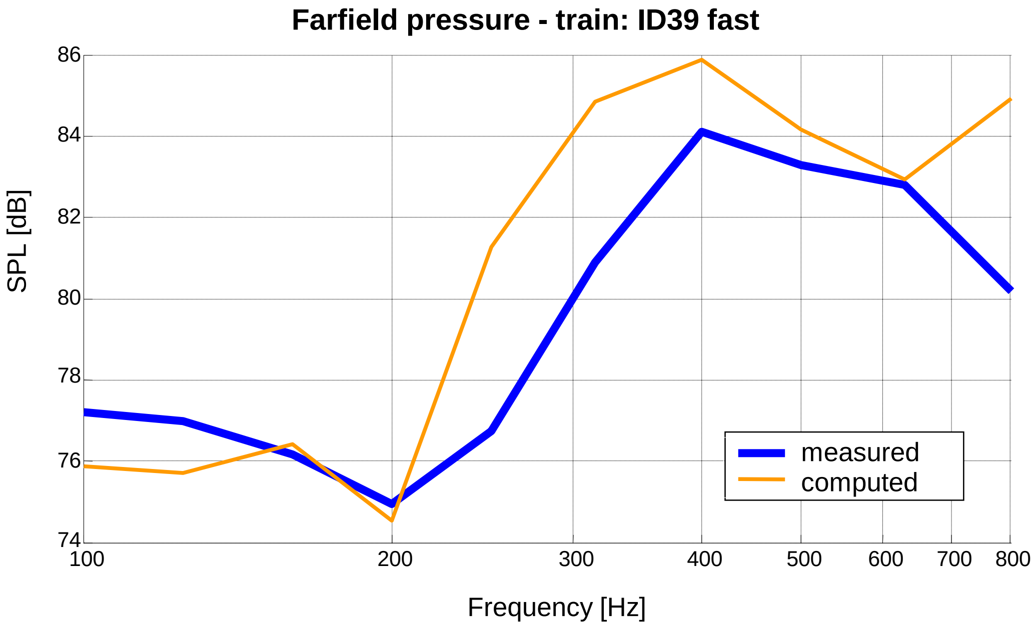


Figure 6: Sound pressure in the farfield point using more realistic excitation

DUNAFERR Lőrinci Hot Rolling Mill: The bearer is deposed in a large hall, which is continued in another hall where the billets are heated. An intensive vibration and a high level noise excite the two buildings originating from the bearer. Therefore not only the thin steel plate wall of the furnace bay radiates but the brick wall of the bearer hall as well (see Figure 7). In a near observation point the noise level exceeds the maximal permissible level, so noise reduction measures have been assessed for the firm. After taking nearfield pressure measurements along the noise vibrating walls and velocity measurements on the brick wall of the bearer hall, statistical BEM was used to determine the participation of different parts of the mill: front-side wall, side wall and roof of the bearer hall, and front-side wall of the furnace bay.

Because of the large dimensions of the buildings, three 2D cuts of the halls have been modelled (Figure 8). The continuous walls of each cut have been spilt into 1 m large “plates” vibrating with random phases. The only free parameter of a wall was the amplitude of its vibrating panels. Nearfield pressure measurements have been used to compute

The side wall of the bearer hall

The front-side wall of the furnace bay and the bearer hall

Figure 7: Parts of the DUNAFERR Lőrinci Hot Rolling Mill

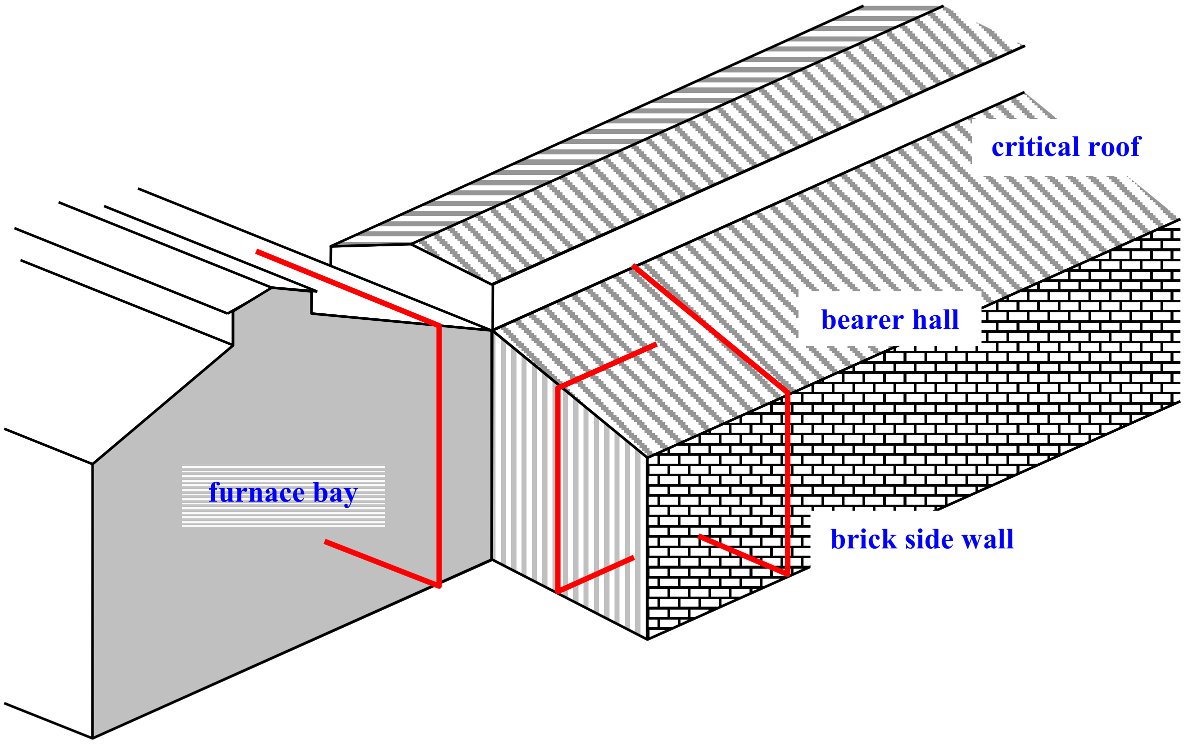


Figure 8: Schematic drawing of the mill (red curves indicate the 2D cuts)

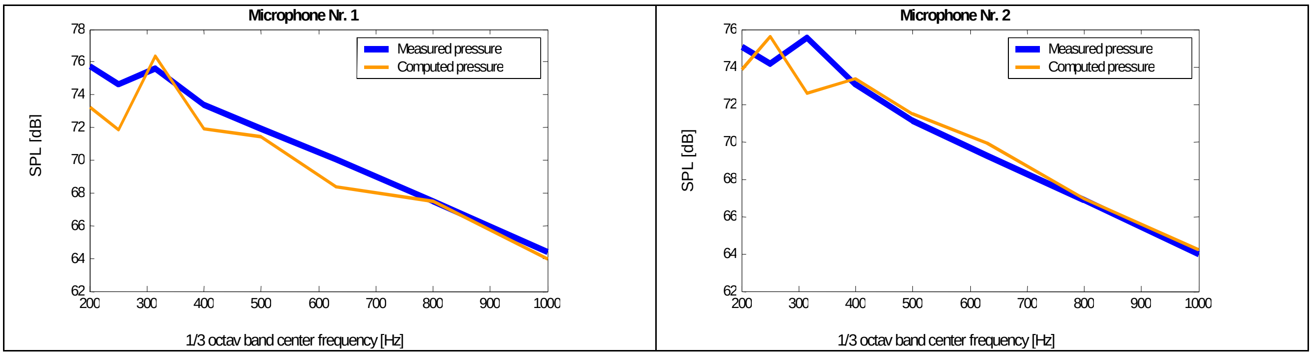


Figure 9: Measured (fat blue curve) and computed (based on estimated surf. velocities – thin orange curve) nearfield pressures - furnace bay

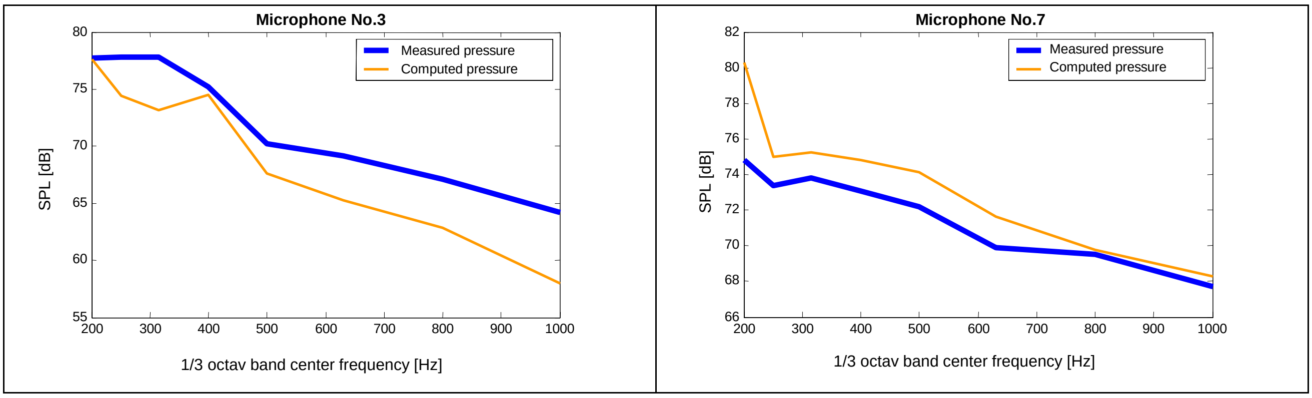


Figure 10: Measured and computed nearfield pressures in front of the bearer hall's side wall – worst fittings

these amplitudes. To verify our assumptions (independent phases, but the same amplitude for all plates on a single wall) the pressure was computed based on vibration results. In the case of the front-side wall of the bearer hall and the front-side wall of the furnace bay the results were quite good (see Figure 9). In the case of the long sidewall combined with the approx. 30° angled roof, the results indicated some modelling errors (Figure 10). In this cut we also had direct vibration measurements, which could be compared with the computed ones. Not surprisingly, the difference was also remarkable. After further examination of the effect, two main causes could be held responsible for those errors: the approx. 2 cm thick gap between the wall and the roof, where noise can be emitted directly from the hall, and the not homogeneous vibration the roof. This is a thin, channelled aluminium plate fixed on long I-beams of which the vibration couldn't be approximated by simple plate vibrations. Unfortunately, because of static and security reasons we couldn't perform detailed vibration measurements. Therefore, the merely one measurement point on the roof couldn't be taken as good input data. To overcome this problem, we simply averaged the measured and computed vibrations and used this data to compute the farfield pressure.

On Figure 11 we see the pressure in the farfield observation point. As can be seen, the computed (green curve) results follow the measured ones (blue curve) fairly well. Due to the power of the method, the computed pressure can be decomposed into noise contributions (red and cobalt green curves) originating from the different parts of the factory.

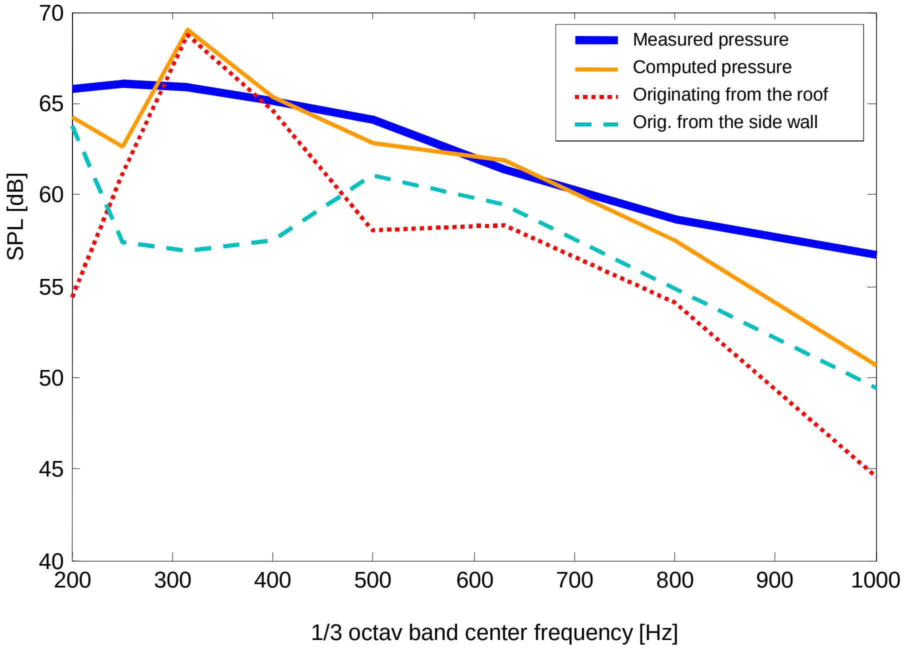


Figure 11: Measured (fat blue curve) and computed (thin orange curve) farfield pressures and this last's decomposition (dotted red and interrupted cobalt green curves)

6 Conclusions

A new method to estimate farfield noise radiation of large objects has been shown and two examples demonstrated the power of the method. Because of the few input data required for the computations, the method can be effectively combined with the Inverse BEM, hence the name of the method: Statistical-Inverse Boundary Element Method. It seems to work quite well; it cannot be approved that the results are 100 % correct, it has been shown, however, that the generated sophisticated surface vibrations give good results in the farfield. Further researches are needed to find some rules of thumb to specify "nearfield" and "farfield" and to verify the method on other objects. In this state, however, the estimations for the relative contribution of different parts of the noise source – handled with care – can already be used for noise control measures.

References

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