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OPTIMISATION OF SOUND INSULATION AT LOW FREQUENCIES

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1. INTRODUCTION

The following paper addresses the optimisation of sound insulation at low frequencies. The expression 'low frequencies' implies a frequency range where the rooms' dimensions are comparable with the wavelength of sound in the rooms. (i.e. below about 200 Hz). At these frequencies the resonance frequencies of double wall constructions or the critical frequency of stiff single leaves (e.g. concrete walls) are situated normally. Good sound insulation at these frequencies has become more important during the last years but is difficult to achieve due to the physical properties of the partitions. However, not only the properties of the partition determine the sound insulation but also the properties of the rooms. The sound insulation is only valid for the specific case under consideration as shown in work by different authors (e.g. [1], [2]). Although this fact increases the difficulties to predict sound insulation at low frequencies, at the same time it opens the possibility for an improvement of sound insulation by optimising parameters belonging to the room. The functioning of both strategies, optimising the design of the partition and optimising the properties of the rooms will be demonstrated in the following.

2. OPTIMISATION TECHNIQUE

Optimisation techniques have been widely developed during the last years and they are applied to problems from different scientific areas. They have also been used in acoustics where the optimisation of vibration isolation [3] or the minimising of the sound radiation from baffled plates [4] are examples. The main idea is to formulate the problem in the form of a so called objective function $f(x)$ which is supposed to be minimised. The variables x are parameters to be designed (e.g. thickness of the air gap of a double wall construction) in order to obtain a maximum sound insulation. Since these parameters can not be chosen arbitrarily, certain limits (i.e. constraints) have to be formulated (e.g. total weight or total thickness of the construction). In the case of an infinite wall the objective function could be a frequency and angle averaged transmission coefficient. This shows that one can not expect the objective function to be linear for problems of complex character such as considered in this paper. Instead a non linear constrained optimisation has to be carried out. Different algorithms for this purpose are described in literature (e.g. [5]). In the work presented in the following the Sequential Quadratic Programming method (SQP) is used. The method, however, does not guarantee to find a global optimum for the problem but a local one. This means that one has carefully to observe the meaning of results obtained by the numerical procedure and it turns out that some knowledge of the behaviour of the objective function in the parameter space is often of great help.

3. SOUND INSULATION OF INFINITE WALL CONSTRUCTIONS

When considering the optimisation of wall constructions one needs a certain number of degrees of freedom to 'play' with. It is very unrealistic to expect to optimise a simple single leave construction for instance. The result will be the movement of its coincidence frequency out of the frequency range of interest. In the following multi layer systems are considered which hopefully offer sufficient 'space' for an successful optimisation.

Theoretical description of the multi layer systems

The theoretical model used in the following is based on the description of each layer by a transfer matrix $M(\omega, \vartheta)$ which describes the pressure and velocity at one side of the layer as function of pressure and velocity at the other side of the layer. The matrix depends on the properties of the layer, the frequency and the angle of the incident wave. The total construction is then described by a matrix $M_{total}(\omega, \vartheta)$ which is a multiplication of the matrixes of each layer. An extensive use of this method is described for instance in [6]. The models used in this paper have been developed in a master thesis project [7] and includes descriptions of fluids, plates (Euler-Bernoulli theory), and elastic layers (elastic field equations).

Example

A typical construction often causing problems at low frequencies are walls of light concrete. For a wall with a thickness of 0.13 m, a Young's modulus of 8 10^9 N/m^2 and a density of 1300 kg/m^3, the coincidence frequency will be about 190 Hz. To compensate for the reduced sound close to this frequency often a second leave (e.g. 13 mm gypsum board) is added to obtain a double wall. Such a construction will have a fundamental resonance frequency determined by the air gap between the gypsum board and concrete wall which is close to the coincidence frequency. Where to situate the double wall resonance frequency will be solved as an optimisation problem.

All three layers (i.e. light concrete, air gap, and gypsum board are modelled as elastic layers which are rigidly connected to each other. The air gap is assumed to be filled completely by mineral wool. Therefore it is considered as an elastic interlayer even though it might not fully be a correct description. Fig. 1 (left side) shows the reduction index R for a diffuse sound field (i.e. averaged over 0 - 78 degrees incidence) for different widths 'h' of the elastic interlayer as a function of frequency. The results show a local optimum when the resonance frequency of the double wall is placed slightly above the coincidence frequency. This optimum was also found by the optimisation procedure if the starting point was chosen in vicinity of this optimum. As objective function the all three quantities in Fig. 1 (right side) were used. Choosing a starting point of the optimisation procedure above h= 0.023 m, a different optimum (h=0.052) was found which gave a better sound reduction at the coincidence frequency. However for different criteria different optima were found. Choosing the sound insulation in the complete frequency band (i.e. R_{total}) one will always end up with an 'air' gap as big as possible.

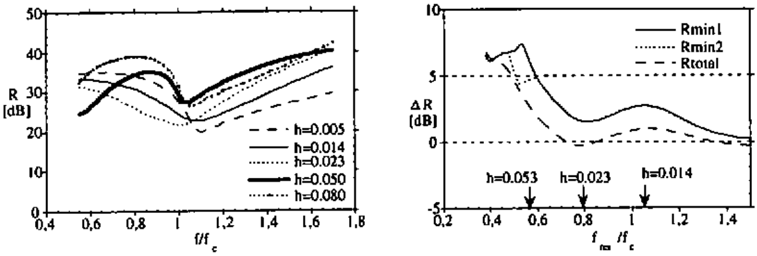

Fig. 1 Left side: reduction index of the double wall construction described for different distance between leaves. Right side: The sound insulation in the total frequency range (Rt_{otal}),the lowest sound insulation in the total frequency range (Rmin2), and the sound insulation at the coincidence frequency (Rmin1) as a function of the resonance frequency of the double wall. All values are related to the values for the highest resonance frequency.

This very simple example demonstrates how careful one has to be when using optimisation techniques. It also shows that depending on the goal the optimisation technique can give suggestions for better constructions which, however have to be verified by measurements. In the case above it shows that as long as one is only interested in increasing the sound insulation at the coincidence frequency it might be sufficient to chose an 'air' gap of 1.5 cm as long as one is satisfied with 3 dB increase. Does one need more the 'air' gap has to be increased to a distance bigger than 4 cm (local optimum at 5 cm). A further increase to 8 cm will not increase the sound insulation at the coincidence frequency substantially but will lead to a better sound insulation at lower frequencies in general.

4. OPTIMISATION OF ROOM PARAMETERS

As mentioned previously the sound insulation between two rooms is not only depending on the properties of the partition but also on room parameters. In a previous project the influence of parameters such as reverberation time, room size or loud speaker position on the sound insulation between two rooms were investigated

[8]. In this work room combination were found where the sound insulation was quite good over all frequencies. These results encouraged us to try an optimisation of the room dimensions in order to obtain optimal sound insulation.

Numerical 'experiments concerning the room size

In [8] different methods are used to describe the sound insulation of partitions between rooms. One method used is the so called 'modal approach' which follows the model used by Donner [2] for a parameter study of the reduction index of small partitions. This methods gives reliable results while the calculation effort is kept at an acceptable level.

Instead of changing room sizes the position of the separating wall was changed in such a way that an optimal sound reduction index was achieved by a certain length ratio between both rooms while the total length (i.e. the length of both rooms together was kept constant). For all cases the height of the rooms was kept constant at 2.5 m. 16 different combinations of pairs of equal rooms were considered, ranging from 3 x 3 m to 6 x 6 m. For each case, the averaged SPL difference was calculated for 41 different positions of the partition, varying within 1 m displacement from the original configuration of equal rooms with the step of 0.05 m. The calculations were carried out for four different walls: two single leaf partitions (20 kg/m^2 and 100 kg/m^2) and two double leaf partitions (f_{res1}= 50 Hz and f_{res2}= 33 Hz). For all walls the coincidence frequency was above the frequency range of interest. Consequently the walls were modelled as a limp plate.

In Fig. 2 the difference of SPL averaged over each room and integrated over the frequency range covering two octaves: 63 Hz and 125 Hz is shown as a function of the displacement of the partition from the original position, at which the rooms were divided into equal parts (which corresponds to the displacement = 0). As it follows from the figure, the SPL difference varies substantially. It attains the minimum value in the case of equal rooms.

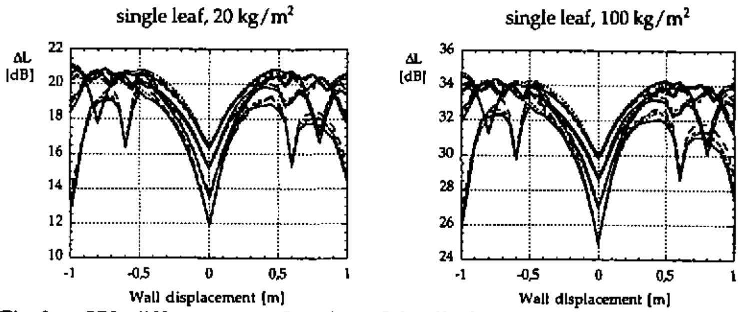

Fig 2. SPL difference as a function of the displacement of the partition from the original position of equal rooms. - case of single wall partitions

The maximum is reached at the partition displacement of nearly exactly 0.50 m, regardless the original dimensions of the rooms. The difference between the minimum and the maximum is near to 8 dB for all investigated cases. The spread of the results for equal rooms configuration is around 5 dB, while it decreases to 2.5

dB near to the maximum at the displacement of 0.50 m. The results for double leaf partitions are shown in Fig. 3. In this case the pattern is less regular. The spread of the results is larger and not decreasing with increasing displacement of the partition. There is no special location giving maximum sound insulation for all cases of room dimensions, opposite to the single leaf partition. This is due to the matching of the resonance frequency with certain eigenfrequencies for different room combinations.

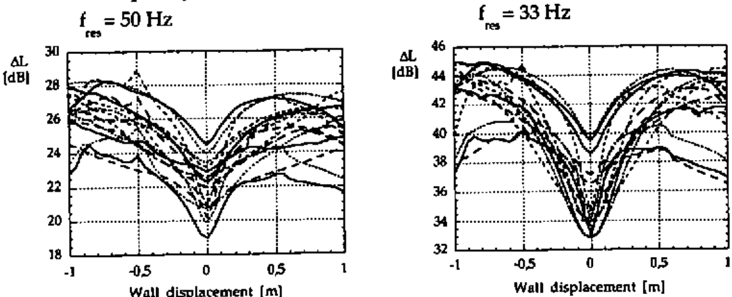

Fig 3. SPL difference as a function of the displacement of the partition from the original position of equal rooms. - case of double leaf partitions.

However, even in this case a 0.5 m shift can be seen as a quasi optimal solution. It is a common experience, that the sound reduction index obtained for the same wall at different laboratories differ at low frequencies. At higher frequencies the SPL difference between rooms increases more rapidly with the wall displacement. Small changes are sufficient to destroy the negative influence of matching modes . The results obtained for the case of the two rooms originally of 4.00 x 5.00 m dimensions are shown in Fig. 4 for 4 octave bands: 63 Hz, 125 Hz, 250 Hz and 500 Hz. In the 500 Hz octave the condition for diffuse field (Schroeder frequency) is fulfilled. Still, the difference between maximum and minimum sound insulation for the same wall amounts to 6 dB. The main variation occurs, however, over shift of only 0.10 m from the location of equal division. For the 63 Hz octave the same change in sound insulation requires displacement of 0.70 m. The likely decrease of reverberation time at higher frequencies can reduce the differences further.

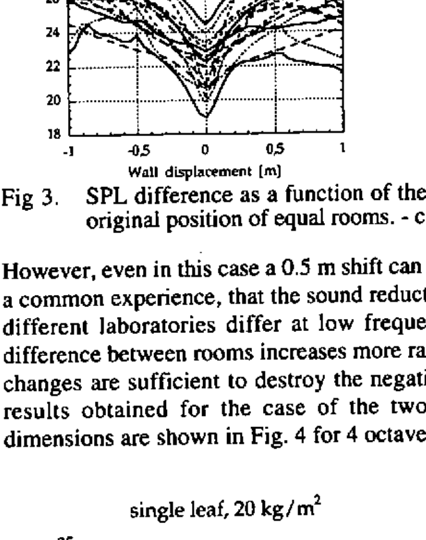

Fig. 4 SPL difference as a function of the displacement of the partition from the original position of equal rooms.

In the case described above optimisation technique was used as well. However, it turned out that due to the long slope running from the minimum towards the nearest maximum the optimal solution was missed when applying the algorithm straight forward to the problem.. The algorithms usually follow the slope while tending to adjust the length of the step automatically in order to minimise the number of steps necessary to find the maximum. Using such automatic step adjustment leads to the increase of step size while following the long slope. Consequently, near to the maximum, the step is large, and it is likely that the maximum will be missed. It finds one of the local maxima situated further away. The obvious, first one, is missed see Fig. 5. A more detailed description of the problem can be found in [9].

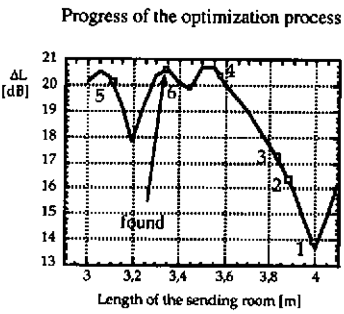

Fig. 5 Progress of the optimisation process (numbers indicating steps)

5. CONCLUSIONS

The examples in this paper demonstrate some possibilities to use optimisation techniques in order to increase the sound insulation at low frequencies. Experience with the technique showed, however, that its use has to be based on the insight of the physical problem. Two ways of optimisation are possible, the optimisation of the partitions design parameters and the optimisation of parameters not belonging to the partition (e.g. the room dimensions) The latter is quite important since unfortunate parameter combinations can 'desctroy' the good properties of the partition.

[1] M Heckl, K Seifert, Eigenresonanzen von Messräumen, Acustica, Vol 8, pp. 212-220.(1958)

[2] U Donner, Parameterstudien zur Luftschalldämmung kleiner Bauteile, PhD Thesis, Berlin(1989)

[3] R Mayne, Optimisation techniques for shock and vibration isolator development, The Shock and Vibration Digest, 8(1), 87-94, (1978)

[4] J S Lamancusa, H A Eschenauer, Design optimisation methods for rectangular panels with minimal sound insulation, AIAA Journal, Vol. 32, No 3,(1994)

[5] R Fletcher, Practical methods of optimisation, Second Edition, John Wiley&Sons, (1991)

[6] J F Allard, Propagation of sound in porous media, Elsevier Applied Science, London, (1993)

[7] J Stenbaek, Optimisation of Sound Insulation and Sound Absorption, M.Sc. Thesis, in print, (1996)

[8] T Kihlman, et al. , Sound insulation at low frequencies, Report D10:1994, Swedish Council for Building Research, Stockholm, 1994

[9] A Pietrzyk, Optimisation od sound insulation at low frequencies by selecting partition's location, Nordic Acoustical Meeting, 12- 14 June 1996, Helsinki.