NOVÉ TECHNOLOGIE
VÝZKUMNÉ CENTRUM
ZÁPADOČESKÉ
UNIVERZITY
V PLZNI

AUTORIZOVANÝ SOFTWARE

ACOUSTIC-PY

FINITE ELEMENT MODELING OF ACOUSTIC TRANSMISSION THROUGH PERIODICALLY PERFORATED INTERFACES

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Název výsledku česky:

ACOUSTIC-PY: *modelování akustického přenosu na periodických rozhraních pomocí metody konečných prvků*

Název výsledku anglicky:

ACOUSTIC-PY*: finite element modeling of acoustic transmission through periodically perforated interfaces*

Abstrakt k výsledku česky:

Program využívá konečně-prvkový řešič SfePy (simple finite elements in Python), který je napsán v jazyce Python a používá knihovny SciPy a NumPy, k numerické simulaci šíření akustických vln na perforovaných rozhraních ve 2D nebo 3D. Matematický popis problému je založen na dvou-škálové metodě homogenizace, jež definuje (sub)problémy na mikroskopické a makroskopické škále. Obě tyto úlohy a také interakci mezi nimi řeší vyvinutý program.

Abstrakt k výsledku anglicky:

The software is based on the general finite element solver SfePy (simple finite elements in Python), written almost entirely in Python and using SciPy and NumPy libraries. It is used to numerical modelling of acoustic transmission through periodically perforated interfaces in 2D or 3D. The mathematical model is based on two-scale method of homogenization which gives the (sub)problems at the microscopic and macroscopic scales. The subproblems and its interactions are solved in the developed software.

Klíčová slova česky:

metoda konečných prvků, akustický přenos, dvou-škálová metoda homogenizace

Klíčová slova anglicky:

finite element method, acoustic transmission, two-scale homogenization method

Vlastník výsledku:	*Západočeská univerzita v Plzni*
IČ vlastníka výsledku:	*49777513*
Stát:	*Česká republika*
Lokalizace:	http://www.zcu.cz/ntc/vysledky/sw/NTC-07-10.html
Licence:	*ANO*
Licenční poplatek:	*NE*
Ekonomické parametry:	*Ekonomické přínosy programu spočívají v možnosti provádět optimalizační výpočty akustických systémů s perforovaným rozhraním, jako jsou např. výfukové systému nebo vlnovody, a tím dosáhnout jejich zkvalitnění.*
Technické parametry:	*Luděk Hynčík, Západočeská univerzita v Plzni, Nové technologie - Výzkumné centrum v západočeském regionu, Univerzitní 8, 306 14 Plzeň, 377634709,* hyncik@ntc.zcu.cz

Documentation of *AcousticPy*

AcousticPy software is based on the general finite element solver *SfePy* (simple finite elements in Python, [1]), written almost entirely in Python and using SciPy and NumPy libraries. It is used to numerical modelling of acoustic transmission through periodically perforated interfaces in 2D or 3D. The mathematical model is based on two-scale method of homogenization [3] which gives the problems at the microscopic and macroscopic scales. The subproblems and its interactions are solved in the developed software.

1 Mathematical model

We consider the acoustic transmission through thin perforated interface plane separating two half-spaces occupied by the acoustic medium. On this interface the homogenized transmission conditions are imposed, these can be obtained as the two-scale homogenization limit of the standard acoustic problem imposed in the layer with an immersed sieve-like obstacle featured by a periodic structure, see [7]. For such a multiscale model the sensitivity of the outer acoustic pressure field w.r.t. the perforation design was developed in [6].

The limit model involves some homogenized impedance coefficients depending on the so-called microscopic problems; these are imposed in the reference computational cell Y embedding an obstacle S the shape of which can be designed. This homogenization approach allows for an efficient treatment of complicated perforation designs of perforations.

2 Running simulation

The software consists of two parts, the first one solves the problems on the representative volume element which reflect the geometrical arrangement of periodic perforation and gives the homogenized acoustic coefficients. The second part uses the coefficients for computation of the acoustic pressure in a given macroscopic domain.

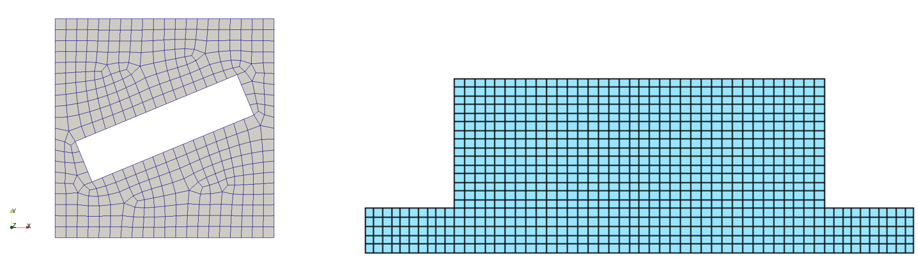


Figure 1: The periodic reference cell representing the perforated structure and the global domain.

2.1 Homogenized parameters of the perforated interface

The "homogenization engine" of *SfePy* is used to solve the problem defined on the periodic reference cell. The program is called as

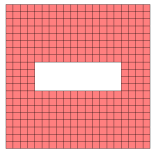
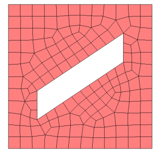
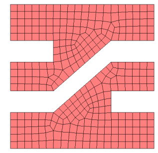
	Mic. 2D/#1	Mic. 2D/#2	Mic. 2D/#3
			
A	0.843	0.691	0.543
B	0.0	-0.251	-0.897
F	-1.660	-1.557	-6.602
$volY$	0.880	0.880	0.760

Table 1: Homogenized coefficients A, B, F, $volY$ for 2D structures.

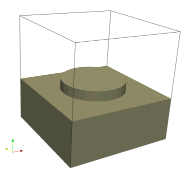
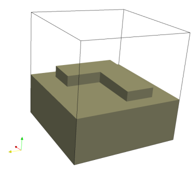
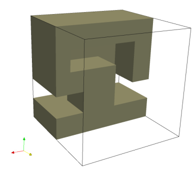
	Mic. 3D/#1	Mic. 3D/#2	Mic. 3D/#3
			
A	$\begin{bmatrix} 0.837 & 0 \\ 0 & 0.837 \end{bmatrix}$	$\begin{bmatrix} 0.839 & 1.767 \cdot 10^{-3} \\ 1.767 \cdot 10^{-3} & 0.834 \end{bmatrix}$	$\begin{bmatrix} 0.640 & 0 \\ 0 & 0.695 \end{bmatrix}$
B	$\begin{bmatrix} 0.0 & 0.0 \end{bmatrix}$	$\begin{bmatrix} 0.0 & 0.0 \end{bmatrix}$	$\begin{bmatrix} -0.142 & -0.142 \end{bmatrix}$
F	-2.064	-1.938	-3.340
$volY$	0.856	0.857	0.736

Table 2: Homogenized coefficients A, B, F, $volY$ for 3D structures.

```
./homogen.py acoustic_micro.py
```

The homogenize coefficients are stored in $HDF5$ file `output/acoustic_coefs.h5` and in text file `output/acoustic_coefs.txt`.

According to the internal variables is_sa and $is\_parametric$ in `acoustic_micro.py` the program can be run in several modes. If is_sa is set to $False$ the program return only homogenized acoustic coefficients A, B, F, $volY$. If is_sa is set to $'scale'$ or $'rotate'$ then it returns the homogenized coefficients and also their sensitivities with respect to the given transformation.

To check the correct computation of the coefficients sensitivities the finite differences can be evaluated by setting $is\_parametric$ to $'True'$. As the result, the finite differences and sensitivities of the coefficients, are compared in the table, see below.

```
Acoustic coeficinets
A: [[ 85877.51964968]]
B: [-0.24470788]
F: -1.77123489094e-05
Vol_Y: 0.839999995639
```

```
Scaling
sA -     grad:  [[-36737.35682578]]  finite diff:  [[-36737.35678603]]
sB -     grad:  [-0.61155497]        finite diff:  [-0.61155497]
sF -     grad:  -2.22979743741e-05   finite diff:  -2.22979736312e-05
sVol_Y - grad:  -0.160000004361      finite diff:  -0.160000005356

Rotation
sA -     grad:  [[-42343.81593044]]  finite diff:  [[-42343.83780567]]
sB -     grad:  [-0.32667727]        finite diff:  [-0.32667721]
sF -     grad:  1.38736959826e-05    finite diff:  1.38737239233e-05
sVol_Y - grad:  -1.08420217249e-18   finite diff:  -7.77156117238e-10
```

The computation of only the homogenized coefficients involves solution of two microscopic subproblems for the unknown corrector functions π^α and ξ, see [7]. The sensitivity analysis is more complicated, because the auxiliary elastic problem at the microscopic level must be solved in order to obtain the design velocity field which is necessary in evaluation of the coefficients sensitivities, see [6]. The boundary conditions of the auxiliary problem reflect the perturbation of a perforation design, i.e. scaling or rotation.

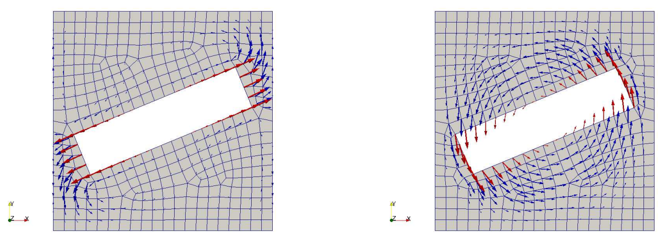


Figure 2: Design velocity field for scaling and rotation.

When the finite differences are required the finite element mesh must be transformed according to the sensitivity task. To get the mesh consistent with the design velocity field the another auxiliary elastic problems with boundary conditions corresponding to the scaling or rotation are solved for small variations $+\delta$ and $-\delta$. The resulting displacements are added to the original mesh and the homogenized coefficients are evaluated for these modifications. Finally the central difference scheme is applied to get the finite differences.

2.2 Computation of acoustic pressure

The standard *simple SfePy* solver is employed for the global problem of the acoustic medium in a given domain.

```
./simple.py acoustic_macro.py
```

At first, it calls the homogenization engine to obtain homogenized parameters of the periodic perforation, then the problem of complex acoustic pressure is solved. The post-process routine evaluates the transmission loss values for a rule defined by internal variable *tl_method* in `acoustic_macro.py`.

The functions defined in `acoustic_macro.py` can be used for:

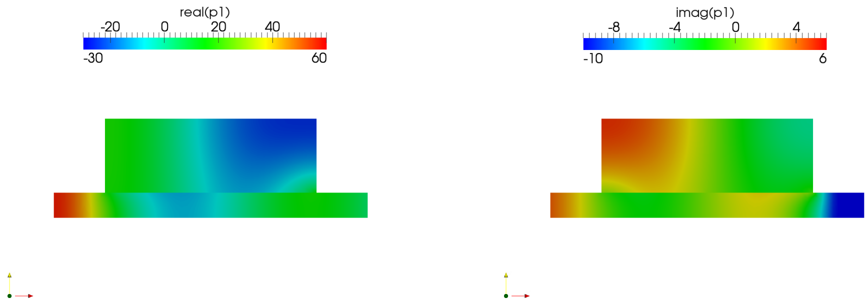


Figure 3: The global problem: real and imaginary part of the acoustic pressure.

- parametric analysis to get the transmission loss curves for a given range of wave number, see [2, 4]
- sensitivity analysis of global acoustic problem with respect to the design of the microscopic perforation; it involves the solution of the adjoined problem, see [6]
- validation of sensitivity analysis which is compared with the finite differences
- optimization of the global acoustic response, [6, 5]

References

[1] http://www.sfepy.org/

[2] Bonnet-Bendhia, A. S., Drissi, D., Gmati, N., Mathematical analysis of the acoustic diffraction by a muffler containing perforated ducts, Mathematical Models and Methods in Applied Sciences, 15(7), (2005) 1059–1090.

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