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A CFD Based Identification Method Of The Transmittances For the Pulsating Gas Installation Element Part II: Experimental Validation

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A CFD BASED IDENTIFICATION METHOD OF THE TRANSMITTANCES FOR THE PULSATING GAS INSTALLATION ELEMENT PART II – EXPERIMENTAL VALIDATION

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ABSTRACT

The theoretical basis for the CFD identification procedure for the installation element is shown in part I. The identification procedure allows to determine, on the basis of the CFD simulation, four independent transmission matrix elements. The example of calculation using the worked out model is shown here for a pulsation muffler of special design. The simulation model for the muffler has been prepared using PHOENICS CFD simulation program. The time dependent pressure changes and mass flux changes at the inlet and outlet cross section of the muffler for step or impulse function excitation is shown in the paper. Also the results of transmittances calculation for this muffler are shown. The comparison shows that the CFD based method gives much better results than classical Helmholtz model. Those results are comparable to those obtained by experimental identification.

NOMENCLATURE

b : flow damping coefficient
c : sound velocity,
$\dot{m}$: mass flow rate,
L : length,
p : pressure,
S : cross section area,
w : velocity,
τ : time,
ω : frequency.

Complex values
$j = \sqrt{-1}$: imaginary unit,
P: complex pressure (after FFT),
M: complex mass flow rate (after FFT),
T: transmittance,
$\mathbf{A} = \{a_{ij}\}$: four pole matrix,
$\mathbf{Z} = \{z_{ij}\}$: impedance matrix,

1. CFD IDENTIFICATION APPLIED TO MUFFLER OF SPECIAL DESIGN

The method developed in this work was applied to the pressure pulsation muffler shown in Fig.1.1 [1][2].

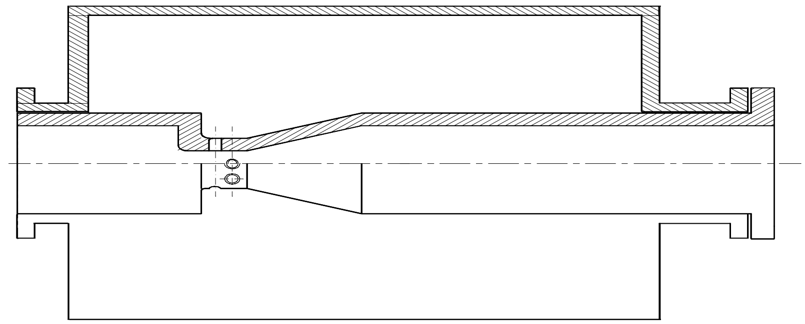


Figure 1.1. The design of the pulsation damper used for the verification.

A simulation model of the muffler was created in cylindrical coordination system, using axial symmetry, which reduced the case to a two-dimensional one. A geometric model was introduced into the PHOENICS ver. 3.1 program. The POENICS CFD program is based on the Finite Volume Method, which is a special formulation of FDM. The governing equations of fluid flow are integrated over all the finite control volumes of the solution domain. The resulting statements express the conservation of relevant properties for each cell. This is related directly to physical conservation law for each property. The program has very wide set of options, allowing calculation using different gas state models, turbulence models, it is possible to use normal Cartesian grid as well as Body Fitted Coordinate curvilinear grid.

Also heat transfer and chemical reactions could be simulated.

According to the formulas shown earlier the boundary conditions for the investigated case were prepared. At the inlet to the muffler a step or impulse function excitation was given evenly at the whole inlet cross-section. The velocity condition was applied with the amplitude of 10[m/s]. At the outlet a rigid wall or a constant pressure outlet condition was applied respectively.

Along the radius the grid contained 39 unequal elements resulting from geometry and 86 along the symmetry axis. The average size of the grid was 1[cm], however near the choking part of the inner tube it was more dense. The reaction time of the muffler for the excitation was simulated within a time range $0 \div 2$ [s] divided unevenly (more densely at the beginning) into 131 parts. This was long enough to obtain required response. An ideal gas equation of state and k-ε turbulence model were used for simulation.

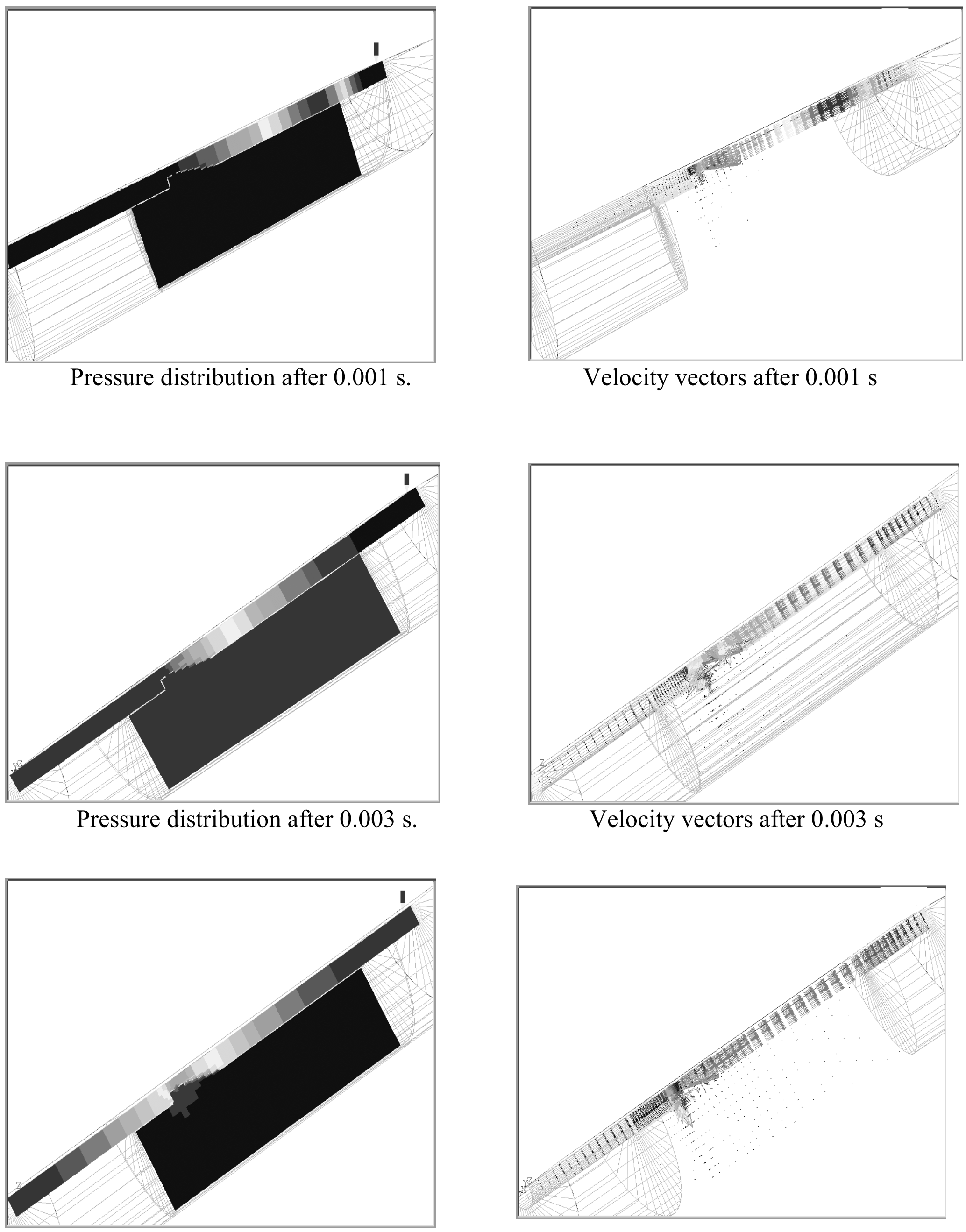
On the fig. 1.2 waves of pressure and velocity traveling along the symmetry axis of the analyzed element is presented. In order to use the CFD calculation results in the Helmholtz model the values of pressure function and mass flow rate were averaged at the inlet and outlet cross section. Based on the diagrams (fig. 1.3) obtained for a step and impulse mass inflow excitation the parameters of the first and second order transmittances were determined.

First order transmittance (only damping and time lag) has a form:

$$\mathbf{T}(s) = \frac{K}{1 + s \cdot \zeta} \cdot e^{-s\Delta\tau} \tag{1.1}$$

Second order transmittance has a form:

$$\mathbf{T}(s) = \frac{K \cdot \omega_o^2}{s^2 + 2\zeta\omega_o s + \omega_o^2} \cdot e^{-s\Delta\tau} \tag{1.2}$$

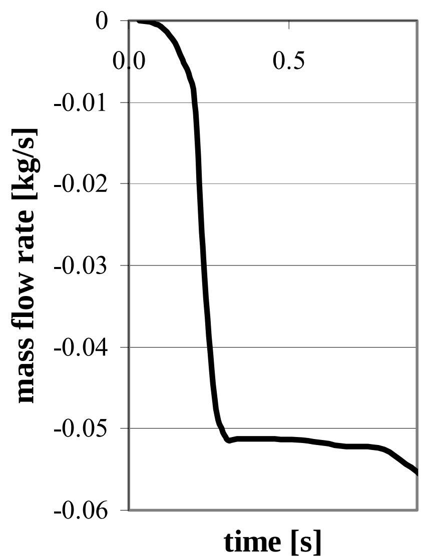


Pressure distribution after 0.001 s. Velocity vectors after 0.001 s

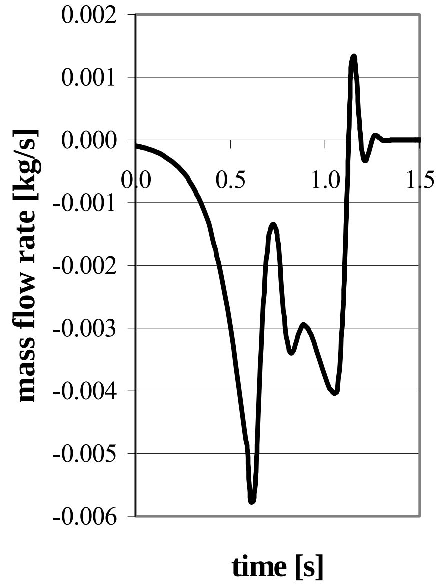
Pressure distribution after 0.003 s. Velocity vectors after 0.003 s

Pressure distribution after 0.01 s. Velocity vectors after 0.01 s

Figure 1.2. Examples of CFD simulation results: isobars and velocity vectors.



Response for step function excitation.



Response for impulse excitation

Figure 1.3. Examples calculated acoustic response of the muffler – basis for transmittance calculation.

The coefficients K, ζ, ω_o, $\Delta\tau$were determined graphically from the time response diagrams of the $\dot{m}_i(\tau)$ and p(τ) functions. The values of K, ζ and $\Delta\tau$ for the second order transmittances (1.2) are the same as the values obtained for the first order transmittances (1.1). The frequency ω_o was determined by measuring the time between subsequent crests of the wave. The results are gathered in Table 1.1.

Table 1.1. Values of coefficients in the 1.1 and 1.2 formulas.

Transmittance	**K**	$\boldsymbol{\omega_o}$	$\boldsymbol{\zeta}$	$\boldsymbol{\Delta\tau}$
$\mathbf{T_a}$	**28154**	**22**	**0,053**	**0,187**
$\mathbf{T_b}$	**-0,8**	**35**	**0,095**	**0,186**
$\mathbf{T_c}$	**46154**	**22**	**0,060**	**0,190**
$\mathbf{T_d}$	**-1,12**	**35**	**0,130**	**0,185**

2. EXPERIMENTAL VERIFICATION OF THE DEVELOPED METHOD

In order to verify experimentally the results of the theoretical identification an experimental set-up was constructed based on air compressor S2P216 operating in the Ward-Leonard system with variable rotational speed (Fig.2.1).

In this test stand the studied muffler was assembled on the suction line of a compressor. A measurement system consisted of DISA capacity transducers coupled through a converter and amplifier to a transient recorder MC101, and next to a PC. The measured P2 curves were compared with the calculated values.

The calculated values of transmittances were used to evaluate pressure pulsations at the P2 point based on the measured curves at the P3 point. In this way the interaction of the studied muffler was simulated on the basis of its computed characteristics. A method of a pressure wave decomposition into a traveling and backward component which was applied here had been earlier described by the author in [3] and [4]. Therefore it will not be presented here.

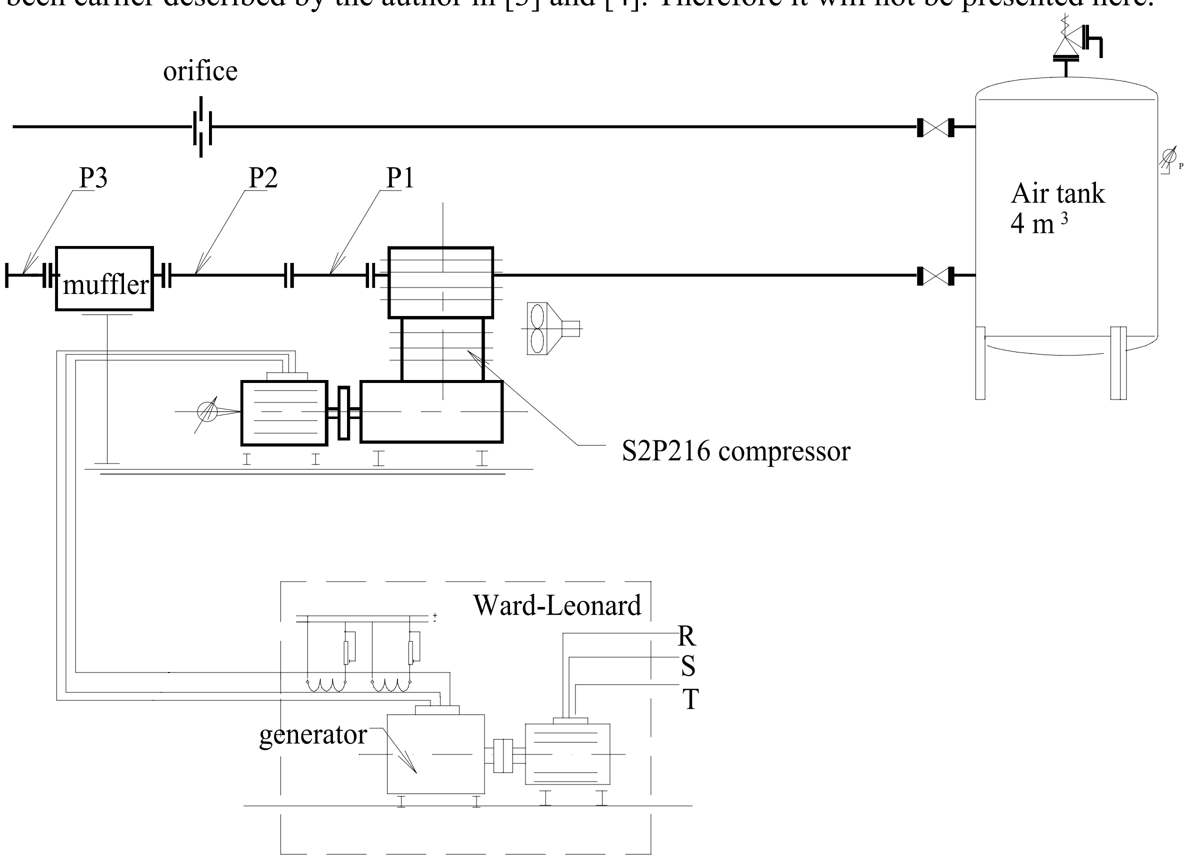
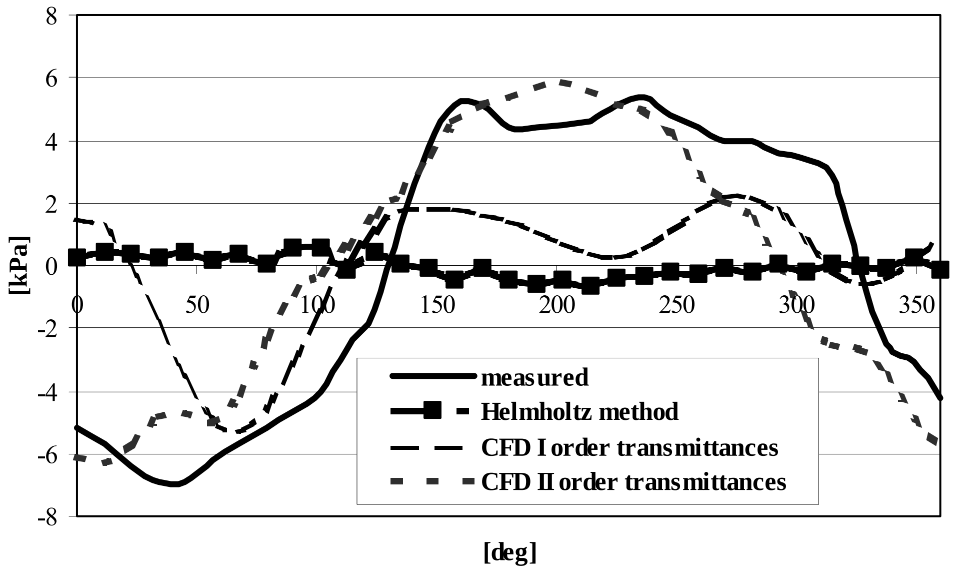


Figure 2.1 Test stand for the identification of the manifold element.

Fig.2.2 present a comparison of pressure curves obtained at the P2 point using a first and a second order transmittances (1.1) (1.2) with the experimental results. A comparison of the significant harmonics obtained from curves presented on Fig. 2.2 is shown in Fig. 2.3. As can be seen, even first order transmittances calculated on the basis of CFD simulation is a



better approximation of the actual pressure pulsations than the classic Helmholtz model.

Figure 2.2. Comparison of the pressure pulsation curves before the damper (P2) obtained by four methods.

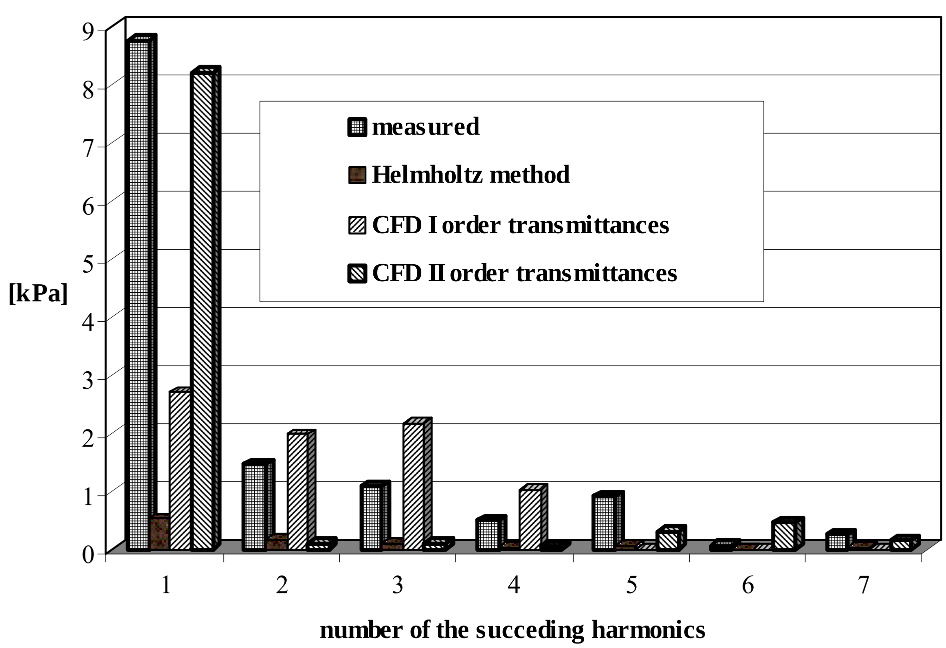


Figure 2.3. Comparison of the harmonic analysis results for the curves from Figure 2.2.

Table 2.1. Comparison of the peak-to-peak amplitudes of pressure pulsations.

[rpm]	**Experiment**	**Helmholtz method**		**CFD simulation I order**		**CFD simulation II order**	
	Δ*p* [kPa]	**Δ*p* [kPa]**	**error [%]**	**Δ*p* [kPa]**	**error [%]**	**Δ*p* [kPa]**	**error [%]**
1300	**12,3**	**1,2**	**90 %**	**7,5**	**39 %**	**12,2**	**1 %**

The results of the calculations are summed up in Table 2.1 A significantly better agreement with the experiment is seen for the CFD based method as compared to the classic Helmholtz model.

The results of the identification obtained with the use of CFD modeling are very promising. Even a simple first order model gives a better response compared to the classic Helmholtz model.

3. SUMMARY AND CONCLUSIONS

The most important conclusion of this work is that in the manifold the identification of acoustic element parameters based on multi-dimensional simulation model (CFD) is feasible. The author obtained much better results from the developed method than those yielded by the classic Helmholtz model.

In the present work transmittances T_{MP}, T_P were introduced. This approach enabled the use of CFD modeling to the identification of parameters of a generalized Helmholtz model.

Direct application of CFD method to the entire vast manifold is futile not only because of computation time needed but, above all, because introducing the geometry data into the program is a very time consuming task. Therefore it is more convenient to perform the identification of parameters i.e. of transmittances T_{MP} and T_P. The method is based on the fact that, assuming linearity, the Laplace transform in the system response to an impulse or step function excitation gives a complex transmittance of a system. Having transmittances T_{MP} and T_P, the four-pole matrix $\{a_{ij}\}$ and impedance matrix $\{z_{ij}\}$ elements can be easily calculated on the basis of formulas shown in Part I of the present work.

The conclusions resulting from the application of this method are as follows:

CFD simulation based method of the identification of objects with complex geometry gives better results for the pressure pulsations amplitude than the classic Helmholtz model, even when a first order transmittance containing only damping and time lag is used. Taking a second order model with four parameters improves the simulation results and gives better agreement with the experimental results.

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