Study on minor losses around the thermoacoustic parallel stack in the oscillatory flow conditions

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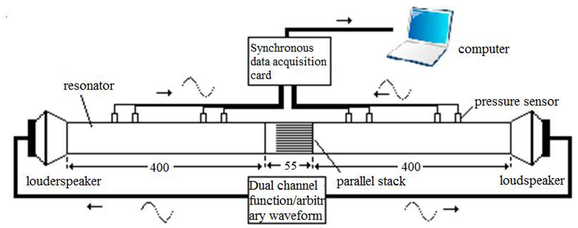
Background

Thermoacoustic devices can achieve conversion between thermal and acoustic energy based on the thermoacoustic effect whereby appropriately phased pressure and velocity oscillations enable the compressible fluid to undergo a thermodynamic cycle in the vicinity of a solid body. Conventional thermoacoustic theory which based on first-order linear theoretical model has its limitations on the nonlinear thermoacoustic effect and phenomenon such as acoustic streaming, vortex shedding and local pressure losses caused by the abrupt change of the cross section. Therefore, the numerical simulation of mathematical equations becomes an important means to solve these problems.

Conclusion

- A close agreement between simulation and experimental result is found, thus providing support for the applicability of the model.
- The vortex structures at the end of parallel stack get larger with the increase of pressure amplitude.
- The real part of minor loss coefficient exponentially increased with the ratio of hydraulic radius and displacement amplitude of oscillatory flow.

Setup



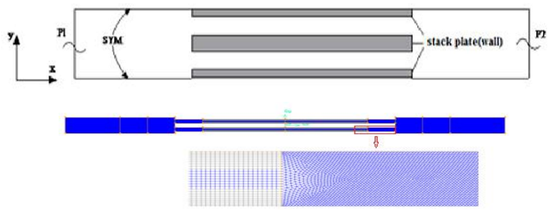
The experimental device consists :

- two loudspeakers
- two resonators
- a regenerator.

The dual channel function/arbitrary waveform generator outputs the sine signal with fixed phase difference and frequency to drive two loudspeakers.

The resonator :28x28mm rectangular stainless steel tube with length of 400mm.
The thickness of stainless steel stack and the spacing between parallel plates is 1 mm, respectively.
The operating gas is atmospheric air under 25°C.

Model



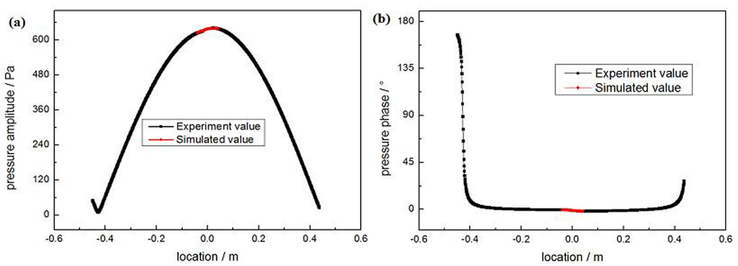
The simulation domain is 80mm long, 4mm high, 410 mm far away from the left-hand side.

The mesh contains about 60619 nodes. Triangular grids are adopted at the ends of stack in order to increase the cell density towards the hydro-dynamically relevant stack areas.

A mesh boundary layer is imposed near the tube walls.

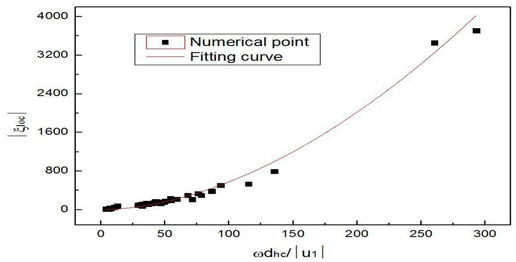
Results

Simulated pressure field comparison with experiments



Experimental pressure field along the thermoacoustic system can be reconstructed using the two-microphone method. And the error of acoustic pressure amplitude between simulations and experiments is no more than 0.23%. The biggest difference in pressure phase is no more than 0.2°.

Minor Losses around the Stack

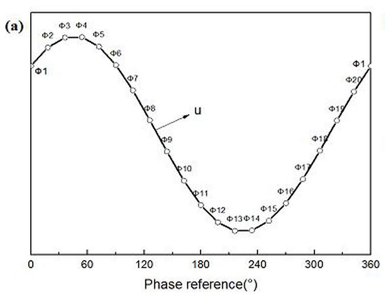


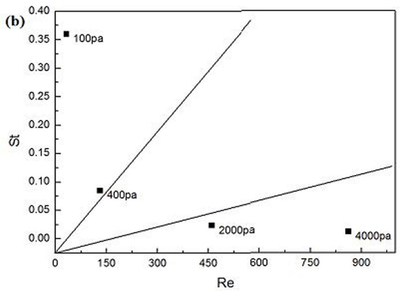
$$\xi_{loc} = \frac{\Delta P(t)}{(1/2)\rho(t)|u(t)|u(t)}$$

$$\xi_{loc} = \frac{3\pi\Delta p_1}{4\rho_m |u_1| u_1} \rightarrow |\xi_{loc}| = 0.141\left(\omega d_h / |u_1|\right)^{1.807}$$

The real part of minor loss coefficient exponentially increased with the ratio of hydraulic radius and displacement amplitude of oscillatory flow.

Velocity oscillation during the timing of 20 phases within the cycle

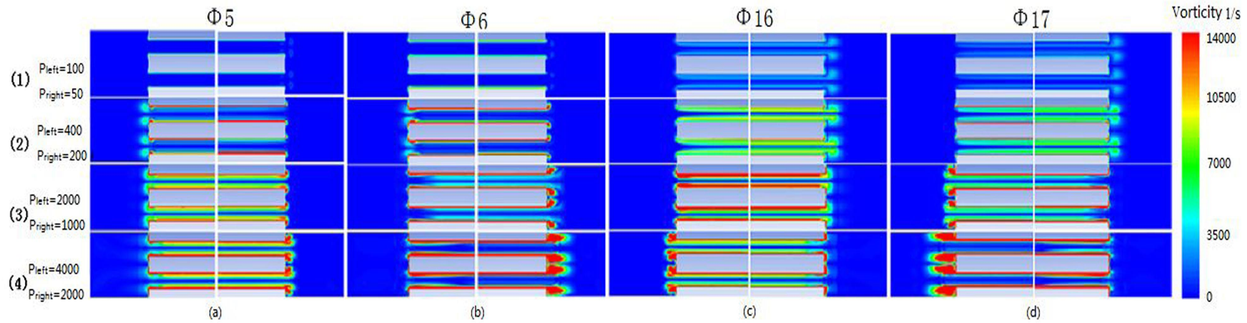




The ratio St/Re is determinative for the category of vortex patterns occurring at the end of a plate. The result is in good agreement of Aben's conclusion.

The vortex size gets larger with the increase of pressure amplitude. In detail, the vertical dimensions of the vortices under forth working condition are larger than the one under third working condition, and the horizontal dimensions of the vortices are roughly two times larger.

Vortex structure under varying pressure



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