Dust Figures in Kundt's Tube – Investigations on the Formation of Ripples

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Introduction

Apart from its technical application, Kundt's Tube is a well-known demonstration experiment in acoustics to visualise standing sound waves. Already its inventor August Kundt described the self-organisation of dust inside the tube to ripple structures. In the 1930s these structures were subject to numerous investigations in order to explain their origin. Visualising the motion of the air inside the tube indicates vortex-systems which develop around the dust particles as the cause of these structures. Modern measurement and visualisation methods support these findings, and give interesting insight into the origin of the dust figures.

Historical Investigations

In 1866 August Kundt [1] describes the set-up to visualise standing waves in a tube with dust figures in the sound field being blown to the nodes of the standing wave.
These experiments were done with semen lycopodii. Using heavier materials such as cork dust, Kundt observed structures of regular spaced ripples at the anti-nodes of the standing wave.
In the 1930s E. N. da C. Andrade [2] was able to visualise the air circulation in the tube's sound field.
According to Andrade's investigations [3], the forces between the particles are due to the developing vortex-systems around the spheres that arrange in the manner that neighbouring vortices just touch.
1932 Andrade explains the formation of the ripple structure by the following process:

- Attraction of particles lying perpendicular to the tube length - repulsion of particles lying parallel to the acoustic particle velocity (PV).
- Particles form lines perpendicular to the acoustic PV.
- Vortices are formed around those lines which repel each other until neighbouring vortices just touch.
- The size of the vortices depends on frequency and amplitude of the sound.
- Gravity stabilises the developing ripples.

Experiments

Equipment

Experiments were carried out in a transparent Kundt Tube with cork dust (diameter of less than 0.6 mm) and styro-foam spheres (diameters: 2.06 mm, 2.64 mm and 3.57 mm).

Ripple structure of cork dust and styro-foam spheres

Phenomenology: Figure 1 shows an example of the ripple structure at the anti-nodes for styro-foam spheres. In addition, a rotation of the spheres around an axis perpendicular to the acoustic PV was observed.

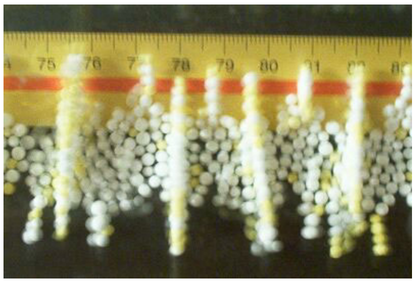

Figure 1: Top view of the ripple structure at the anti-nodes in the tube filled with styro-foam spheres.

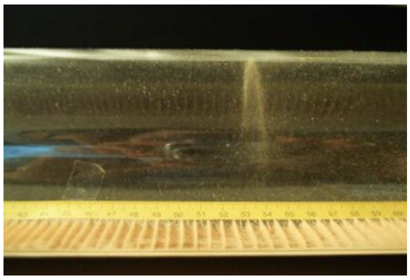

Figure 2: Top view of the ripple structure at the anti-nodes in the tube filled with cork dust.

Ripples with smaller distances were observed with cork dust (cf. fig. 2) and additionally structures on the tube ceiling in the middle of the anti-nodes (described by Andrade [3] as

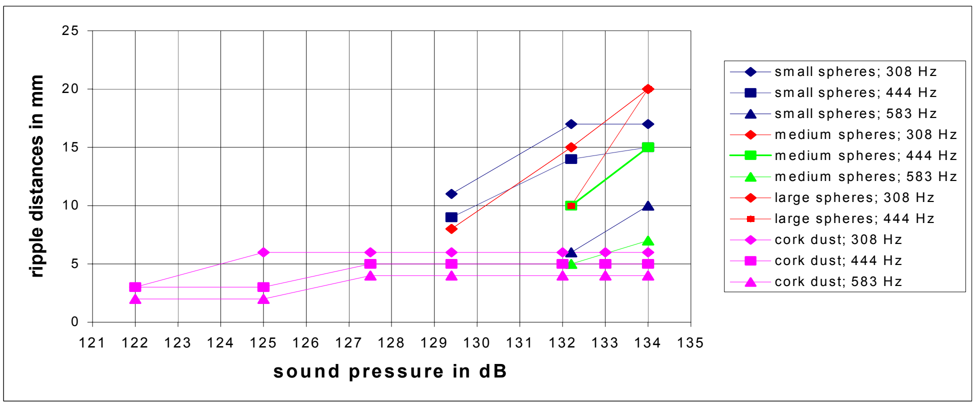

Figure 3: Ripple distances for differently sized styro-foam spheres and cork dust at different frequencies and sound pressures.

discs).

Dependence on sound pressure, frequency and particle size: Distance and height of ripples depend on sound pressure and frequency and size of the particles (cf. fig. 3 & 4):

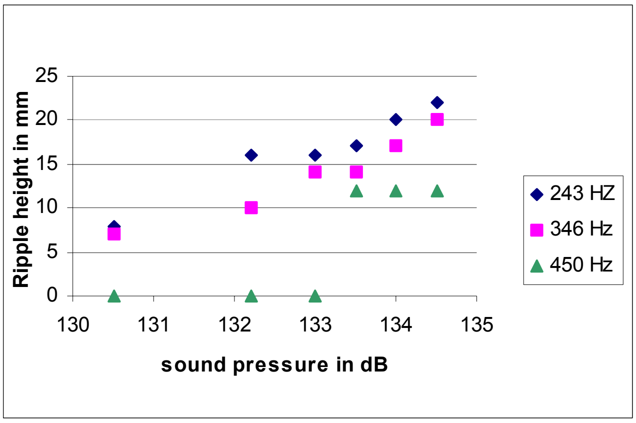

Figure 4: Ripple height for medium sized styro-foam spheres at different frequencies and sound pressures.

A bifurcation of the pattern formation was noticed for cork dust. The distances of ripples double at certain sound pressure.

Vortices

The vortex-systems described by Andrade [4,5] was confirmed by using styro-foam and cork dust at the same time: Cork dust was blown away from the styro-foam ripples (cf. Fig. 5) and the movement of the dust visualised the existence of vortices around the lines of styro-foam.

Figure 5: Side view – Cork dust being blown away near the styro-foam ripples

Pressure measurements

Measurements with a micro-manometer and a low-frequency microphone were carried out to find out whether there are pressure differences inside and near the ripple structure.
The pressure gradient inside one ripple was measured with a micro-manometer and denoted a pressure gradient of up to 10 Pa on about 2 cm vertical distance.
The microphone was pulled through the ripple structure with almost constant speed. The time-signal displays the acoustic standing wave and additionally small pressure peaks at the location of the ripples. According to the calibration, the pressure difference is in the order of 4 Pa. This pressure difference is sufficient to induce a fluid motion to lift the styro-foam spheres and the cork dust from the bottom of the tube.
These pressure differences are coupled to the pattern of particles and do not exist in an empty tube.

Conclusions

Pattern formation was observed in a Kundt Tube for particles of different size. Spacing and height depend on amplitude and frequency of the sound. Andrade's findings on vortex systems that are linked to the pattern formation are confirmed. Evidence was provided that the structure is formed or at least stabilised by pressure gradients that were able to lift the particles.

The process of pattern formation in Kundt's Tube is not yet fully understood. Ripple structures as seen with cork dust or styro-foam spheres can also be produced on liquids [4], which can not be explained by vortex-systems around obstacles. Self-organisation as suggested in [5] might shed additional light on these phenomena.

Acknowledgements

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