Basic idea

• The substructure consists of ribs of powder normal to stream direction

• The ribs are formed due to vortices of the size of the distance between the ribs, which we have observed with a very fine powder

• The vortices form because of:
  • alternating air current in the tube
  • air boundary layer adherence (viscosity)
Experimental approach

- **Parameters:**
  - Tube dimensions (length, radius)
  - Sound intensity
  - Sound frequency
  - Powder material

- **Measured quantities:**
  - Distance between the ribs
  - Number of ribs
• To obtain standing waves in the tube we used two sound sources:
  • Speaker
  • An aluminium rod

Apparatus schematic:
Apparatus cont.

The function generator

The speaker (8Ω/50-20000Hz)

• The greatest advantage of the speaker is the possibility of observing the standing structures
Structure characteristics

• The ribs are highest at the pressure nodes
• The distance between the ribs is getting smaller with increasing frequency
• The ribs appear only at resonance frequencies of the tube
• The structures are very regular to a certain sound intensity, above which turbulences occur
• The ribs can be very high and thin (sometimes just one layer of particles)

• There is continued transport of material between the ribs
• If a very fine powder is used (e.g., carbo animalis) vortex motion can be seen.

• At greater amplitudes of sound the particles levitate and spin because of the abrupt pressure changes.
• With increasing frequency the height of the ribs decreases
• Several powders were applied for the rib formation:

1. Carbo animalis
   • Very light – enables seeing vortices
   • Usually wet

2. Cork powder
   • Not as light, but very dry
   • Gives best structures
**Explanation**

- In the experiment vortex motion of carbo animalis was observed.
- That proves that the cause of rib formation are air vortices.
- An analogy between the Kund structures and sand ripples can be observed:
• The formation of vortices can be approached in phases:

1. **phase**

• In the beginning there is no air motion – the powder stands still

• The resonant frequency of the tube is played

• The powder will aggregate in heaps at the pressure nodes because of the currents
2. phase

- The pressure on one side of a powder heap is greater than the pressure on the other side.
- The air flows towards the lower pressure region:

\[ P_1 < P_2 \]
• Because of friction between the fast air layer and the layer adherent to the powder the faster air drags the slower air lowering the pressure between the points A and B

• The pressure will be equalizing from above because of the greater pressure beyond the heap

• That means that the air gains additional downward velocity:
3. phase

- Now the current direction changes (the current is alternating) and the pressure gets greater on the other side.
- The pressure is still equalizing, but now from downwards.
• **Further time development**

• Because of the alternating current, phases 2. and 3. alternate

• This results in circular motion on both sides of the powder heap:

• The formed vortices will cause the occurrence of new heaps and new vortices

• So the observed regular structures are formed
• If the air velocity increases, the flow will become more chaotic - turbulences
• Additional vortices and nonregular formations form
• This process can be beautifully observed

Regular structures
(low amplitude)  
Turbulences
(high amplitude)
• The vortex intensity is proportional to flow velocity

• Thus the highest ribs are formed at the pressure nodes where the velocity is maximum

• At the velocity nodes there are no ribs because the air doesn’t move there
• The structures occur only at resonance frequencies because only then the sound intensity (and flow velocity) is large enough for vortex formation.

• The distance between the ribs depends on frequency because of simple energy and angular momentum conservation:
  • With increasing frequency the air velocity also increases.
  • This means that the vortices spin faster.
• Angular momentum conservation:

\[ \omega_0 r_0^2 = \omega r^2 \]

\[ \omega \sim \nu \]

\[ r \sim r_0 \sqrt{\frac{\nu_0}{\nu}} \]

• Comparison with the experimental data yields:

Function fit: \( r = a \nu^b \)

Determined parameters \( a \) and \( b \):

\[ b = -0.4864 \approx -0.5 \]

\[ a = 739,8268 \approx 740 \]

as predicted!

- coefficient of proportionality
Conclusion

• Cause of rib forming in Kundt’s tube:
  Vortices formed by
  • The alternating air current
  • Adherent boundary layer of air
• Proof:
  • Vortices detected experimentally
  • The theory gives a correct prediction of the variation of rib distance with frequency of emitted sound