SOME OBSERVATIONS ON THE FORMATION OF STRIAE IN A KUNDT'S TUBE AND ALLIED PHENOMENA

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The facts contained in the following brief historical summary were taken from a paper by Irons.[1]

Kundt,[2] in his original experiments, used a glass tube strewn on the inside with Lycopodium powder. When the tube was properly clamped and stroked with a dampened cloth, the familiar dust figures were formed in the tube. Kundt noticed that, after stroking the tube for some time, circles of powder formed at the nodes on the bottom of the tube. The formation of these circles was attributed in part, at least, to the vibration of the glass tube. In his later experiments he used a glass tube in which the air was disturbed by means of a diaphragm attached to the end of a metal rod,—the form of apparatus commonly used in laboratories today. With this apparatus he observed that on stroking the rod, vertical rings, the planes of which were perpendicular to the axis of the tube, were formed above dust heaps on the bottom of the tube at the nodal points of the air column. Sand and iron filings also were used in the tube. The important conclusion at which he arrived was the fact that, regardless of the shape of the dust figures, the half-wave length of the sand distribution in the tube remained constant.

Dvorak,[3,4] experimenting with water in the bottom of a Kundt's tube, showed that, on stroking the rod, a wall of water was formed across the tube at the antinodes. Also he found that a positive pressure existed at the nodes, and that the air in the sounding tube flowed from a node to an antinode along the center of the tube, and from an antinode to a node along the wall of the tube. This latter fact was later demonstrated mathematically by Lord Rayleigh.[5]

Konig[6] gave an explanation for the formation of striae in a Kundt's tube based on the hydrodynamical equations of Kirchhoff.[7] Konig showed that, having given two spheres of radii R_1 and R_2 separated by a distance r_0 in a vibrating perfect fluid, the components of the forces between them were given by

$$X = -(3/2\pi\rho R_1^3 R_2^3 \omega_0^2 / r_0^4) \sin\theta\,(1-5\cos^2\theta),$$
$$Z = -(3/2\pi\rho R_1^3 R_2^3 \omega_0^2 / r_0^4) \cos\theta\,(3-5\cos^2\theta).$$

where ω_0 represents the velocity of the fluid stream taken parallel to the axis of z, θ is the angle which the line of centers of the spheres

[1] Irons, E. J., Phil. Mag., 7:523. 1929.
[2] Kundt. Pogg. Ann. 127:497. 1866.
[3] Dvorak, Pogg. Ann. 153:102. 1874.
[4] Dvorak, Pogg. Ann. 158:42. 1876.
[5] Rayleigh, Phil. Trans. 175: Part I. P. 1. 1884.
Scient. Papers, 2 p. 239.
"Sound," 2 p. 333. 1926.
[6] Konig, Wied. Ann. 42:353, 549. 1891.
[7] Kirchhoff, Mechanik, 18 and 19 Vorlesungen, or Robinson, Phil. Mag. 19:476. 1910.

"Proc. Ind. Acad. Sci., vol. 41, 1931 (1932)."

makes with the z-axis, and ρ is the density of the medium. The motion was considered as taking place in the xz plane which included the bottom of the tube. Konig considered Y = O, and then when $\theta = n$, where n is an integer,

$$X = 0. \quad Z = 3/2\pi\rho R_1^3 R_2^3 \omega_0^2 / r_0^4,$$
and when $\theta = n/2$,
$$X = -3/2\pi\rho R_1^3 R_2^3 \omega_0^2 / r_0^4, \text{ and } Z = 0.$$

An interpretation of these equations showed that spheres situated in a line parallel to the axis of the tube, i. e., along the direction of sound propagation, repel each other, while spheres situated along lines perpendicular to its direction attract each other. From these facts an explanation of the formation of striae was suggested.

Cook[8, 9] proceeded to test Konig's formulae experimentally and found that,—

(a) When particles were not more than half their diameter apart and had their line of centers at right angles to the air flow, they were maintained in equilibrium. (According to Konig's theory the spheres should be in contact.)

(b) Particles having their line of centers along the air flow and within half of their own diameter, approached each other, formed a system like a Rayleigh disk, and rotated into a plane perpendicular to the line of air flow.

During the past seven years the author of the present paper has been experimenting on striae in a Kundt's tube and on allied phenomena in an attempt to obtain an explanation of the formation of these striae. Incidental to the study proper of striae, a study of a solid glass rod, rectangular in cross-section, was made utilizing the discovery of Biot[10] In this study a series of photographs was made revealing clearly the fact that the strain, in a glass rod clamped midway between its ends and stroked at one end with a dampened cloth, increases from the free end, an antinodal point, towards the center, a nodal point. This was shown by the increase in the blackening of the photographic negative by light passing through the rod and through crossed Nicols as exposures were made at regular intervals along the rod. In a similar manner Kundt[11] has shown that striae exist in a glass rod while it is being stroked.

Furthermore, in connection with the study of a glass rod during the summer of 1925, the author found that when a glass rod was clamped midway between its ends, and on the antinodal portion of which some alcohol had been placed, that when the rod was stroked by a cloth dampened with alcohol, alcohol striae formed on the surface of the rod.

It was found by the author[12] that pith dust, formed by grinding

[8] S. R. Cook, Phil. Mag. 3:471. 1902.

[9] S. R. Cook, Phil. Mag. 6:424. 1903.

[10] Biot, Physique. 2:15. 1828.

[11] Kundt, Winkelmann's "Handbuch", ii. Akustik, p. 324 (1909).

[12] R. V. Cook, Science, 64:404. 1926.
Nature, 118:157. 1926.
Sch. Sc. & Math. 26:722. 1926.

pith from the stalks of sunflower on a fine-grained emery wheel, gave a very light powder found excellent for forming striae in a Kundt's tube. By a method described in the paper above cited, this pith dust was used to produce striae, practically one particle thick, and extending completely across the glass tube. Disks of cork were formed by Abbott[13] with a different arrangement of apparatus.

Striae[14] were formed in a glass tube in which the air column was set into vibration by means of an interrupted air jet, the frequency of which was too low to produce an audible tone.

In order to determine whether or not the striae in a Kundt's tube were due to the vibration of the tube itself, a tube of the form shown in Fig. 1 was used. The tube contained pith dust equally distributed inside it, and it was clamped midway between its ends. The end of the tube was stroked with a cloth moistened with alcohol. When air was present in the tube, very regular striae were formed. When the tube was evacuated, no striae formed, and the pith dust exhibited only a very slight

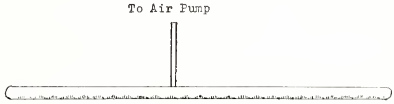

Figure 1.

motion at most. This showed that the presence of a fluid was essential to the formation of striae in a Kundt's tube.

A photographic study of striae was made by the author using a standard motion picture camera. The photograph and diagram of the apparatus used are shown in Plate I and Fig. 2. A glass tube 1 meter long and about 1.8 centimeters inside diameter had some cork charcoal scattered along its inside and a sheet-tin piston connected by means of a copper wire to one prong of an electrically-driven tuning fork was used to excite the air vibrations in the tube. The piston was inserted a short distance into the end of the tube and the other end of the tube was closed with a tight fitting cork. When the fork was made to vibrate, complete disks of cork dust were produced across the tube at the antinodes and for a considerable distance on either side of the antinodal point. Close observation showed that at each disk two adjacent orbits of rotating particles were present, one on each side of a single striation, one clockwise, and on the opposite side a counter-clockwise rotation. Positives made from a portion of the motion picture negative are shown in Plate II.

Figs. 1(a) and 1(b), Plate III, show enlarged photographs of two such striae. The approximately circular motions take place so that the particles leave the top of the striation and enter at the bottom of the same striation. Midway between two adjacent striae little striae lower than the others tend to form but are soon destroyed by the motions mentioned above, the dust particles forming these lower striae being

[13] R. B. Abbott, Purdue University.

[14] Rolla V. Cook, Phys. Rev., 36:1098-1099. 1930.

pulled away in opposite directions and forced into the two adjacent striae at the bottoms of the same. Thus the dust particles are pulled away from a line approximately midway between adjacent striae in opposite directions and forced into the major striae at their bottom portions. Fig. 1(c), Plate III, shows diagrammatically the approximate motion

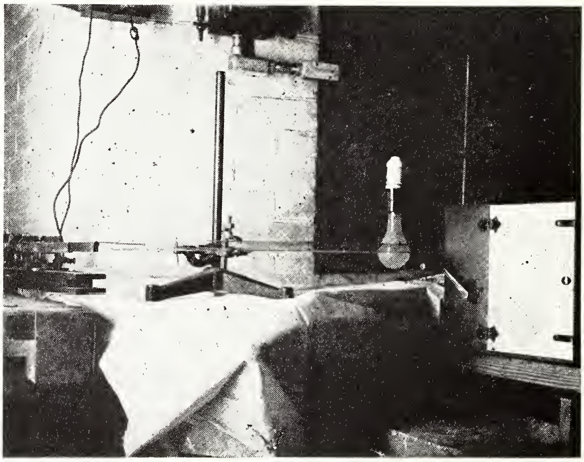

Plate I.

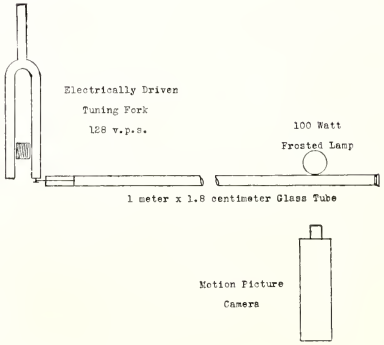

Figure 2.

between adjacent striae. When the agitation of the dust particles is violent, the striae at the antinodes, especially those extending completely across the tube as disks, do not remain always in one position, but very often they merge into each other. On two or three occasions it was observed that, when the amplitude of vibration of the tuning fork was diminished slightly by touching the prong of the fork with the finger, a large circular disk on settling down to a striation of smaller height, would break up into very thin striations, separated by a distance of one millimeter or less.

In the summer of 1927 the author succeeded in maintaining two paper segments cut in a shape similar to a dust striation, upright in a Kundt's tube. When pith dust also was present in the tube, a violent,

Plate II.

somewhat elliptically-shaped rotation about an inch long along its major axis parallel to the axis of the tube, was produced. Also a single segment of paper similar to a dust striation has been maintained upright in the tube for a short time by means of the air vibrations.

The striae in a Kundt's tube are formed by air vortices in the same manner as ripple-marks in sand are formed by water vortices. As shown by Darwin,[15] these rotations are produced when an alternating fluid flow takes place about obstacles in its path. The clockwise and counter-clockwise rotations are maintained always in their respective directions regardless of the fact that the fluid stream is alternating. Fig. 3, (a), (b), and (c) sketched from Darwin's paper shows the directions of

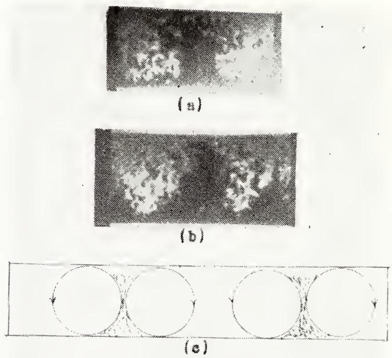

Fig. 1

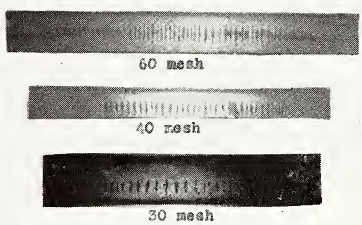

Fig. 2

Plate III.

rotation of the vortices above sand and adjacent to the two sides of a striation during one-half of a complete oscillation of the fluid stream. The respective directions of rotation remain the same for the second half of the complete oscillation. These vortices are probably originally formed by existing superficial inequalities in the level of the layer of

(a) (b) (c)

Figure 3.

dust particles on the bottom of the tube, or by those superficialities formed by shifting dust particles soon after the air in the tube is set into vibration.

A study of the distances between adjacent striae for constant dust particle size and various frequencies was made by means of the apparatus shown in Fig. 4. The data obtained is given in Table I. The air

[15] G. H. Darwin, Proc. Royal Soc., 36:18. 1883.

vibration in the glass tube was produced by means of a cork stopper fitted into the cone of a loud speaker unit which, in turn, was driven by means of amplified electrical impulses obtained by means of an electrical pick-up from Fletcher's[16] standard frequency phonograph records. It was found that, as frequency of air vibration increased, the average distance between adjacent striae became smaller. Plate IV shows enlarged photographs of the striae obtained. The frequency markings are relative values rather than absolute values since the speed of the phonograph was not corrected in order to obtain absolute values.

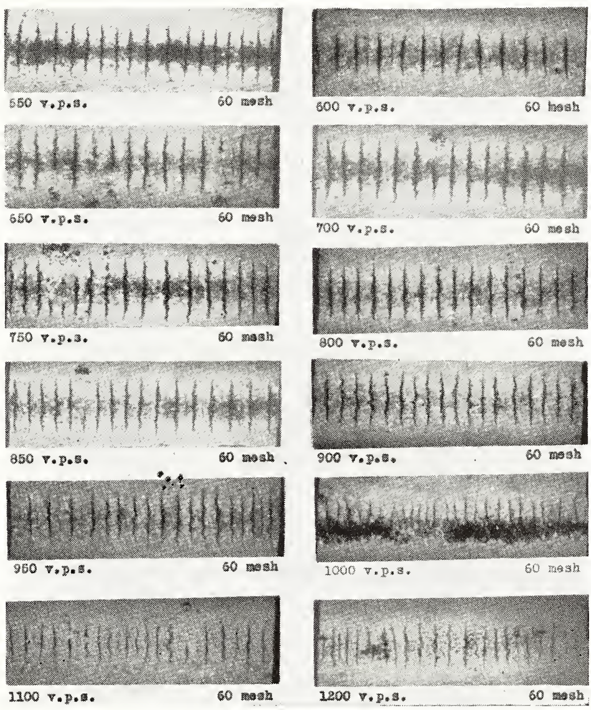

Plate IV.

A study of the distances between adjacent striae for constant frequency and various dust particle sizes was made by means of apparatus very similar to that shown in Fig. 4. The air vibration in the glass tube was produced by stroking a brass rod, (the usual Kundt's method). The photographs of the striae produced, Fig. 2, Plate III, show the striae distances somewhat reduced in size. Table II and Table III give the data taken. Measurements showed that, with a constant frequency of air vibration, the average distance between adjacent striae decreased with decrease in particle size.

[16] Harvey Fletcher, Bell Telephone Laboratories.

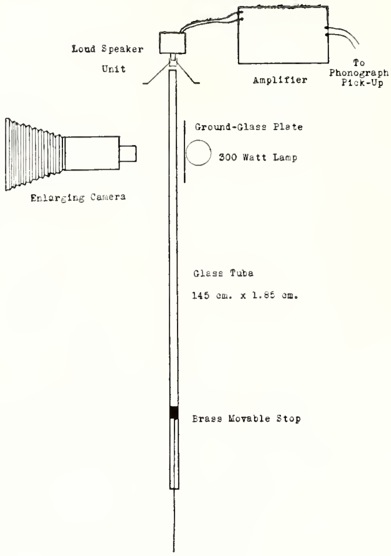

Figure 4.

TABLE I

V. p. s.	No. Spaces in	Length	Average Distance Between Adj. Striae
550.	16.	8.11 cm.	.5 cm.
600.	14.	8.0 cm.	.56 cm.
650.	13.	7.7 cm.	.54 cm.
700.	13.	7.5 cm.	.57 cm.
750.	16.	8.1 cm.	.50 cm.
800.	16.	8.15 cm.	.50 cm.
850.	16.	8.15 cm.	.50 cm.
900.	17.	7.9 cm.	.47 cm.
950.	19.	8.05 cm.	.42 cm.
1000.	23.	8.0 cm.	.30 cm.
1100.	23.	8.0 cm.	.30 cm.
1200.	24.	8.1 cm.	.34— cm.

Particles used = cork particles which passed through a wire sieve having 60 mesh per inch.
Room Temperature, 25°C.
Average Speed of Phonograph Record = 75.25 r.p.m.
Length of Glass Tube = 145 cm.
Diameter of Glass Tube = 1.85 cm.

TABLE II

Cork Dust Mesh/Inch	No. Striae	in Length	Distance Between Striae	Average
30.	31.	7.9 cm.	.25 cm.	
30.	32.	8.0 cm.	.25 cm.	
30.	41.	13.1 cm.	.32 cm.	.308 cm.
30.	40.	13.1 cm.	.33 cm.	
30.	34.	11.6 cm.	.34 cm.	
30.	32.	11.5 cm.	.36 cm.	
40.	59.	12.2 cm.	.20 cm.	
40.	52.	11.5 cm.	.22 cm.	.21 cm.
40.	53.	11.6 cm.	.22 cm.	
40.	61.	12.7 cm.	.20 cm.	
60.	87.	14.1 cm.	.16 cm.	
60.	84.	14.0 cm.	.17-cm.	
60.	74.	12.5 cm.	.17-cm.	.17 cm.
60.	81.	14.0 cm.	.17 cm.	
60.	80.	14.1 cm.	.18 cm.	

Length of Brass Rod = 182.9 cm to disk.
Diameter of Brass Rod = 8.0 mm.
Temperature of Room = 29°C.

TABLE III

Cork Dust Mesh/Inch	No. Striae	in Length	Distance Between Striae	Average
30.	42.	12.5 cm.	.30 cm.	
30.	42.	12.5 cm.	.30 cm.	.30 cm.
30.	36.	11.3 cm.	.31 cm.	
30.	36.	10.0 cm.	.30 cm.	
40.	58.	13.5 cm.	.23 cm.	
40.	49.	11.0 cm.	.22 cm.	.217 cm.
40.	62.	12.8 cm.	.20 cm.	
40.	60.	13.2 cm.	.22 cm.	
60.	63.	11.4 cm.	.18 cm.	
60.	66.	11.5 cm.	.174 cm.	.177 cm.
60.	63.	11.5 cm.	.182 cm.	
60.	67.	11.5 cm.	.172 cm.	

Length of Brass Rod = 182.9 cm. to disk.
Diameter of Brass Rod = 8.0 mm.
Temperature of Room = 35°.5 C.

Summary. The author has shown by the experimental work described in this paper that,—

(a) The strain produced by stroking a glass rod clamped midway between its ends, increases from the antinodal point to the nodal point in the rod.

(b) Liquid striae were formed on the antinodal portion of a glass rod clamped midway between its ends, and stroked with a dampened cloth.

(c) Striae were formed in a glass tube by means of air vibrations, the frequency of which was too low to produce an audible tone.

(d) The presence of a fluid in a Kundt's tube is essential to the formation of striae.

(e) The formation of striae in a Kundt's tube is accompanied by vortices adjacent to the opposite sides of each striation. Such vortices form the striae.

(f) Paper segments similar in shape to a dust striation were maintained upright in a Kundt's tube by means of the vibrating air column.

(g) Using a given dust particle size, increase in frequency of air vibration produces a decrease in distance between adjacent striae.

(h) Using a constant frequency of air vibration, a decrease in dust particle size decreases the distance between adjacent striae.

In conclusion the author wishes to thank Dr. A. L. Foley, Dr. Mason E. Hufford, Dr. J. B. Dutcher, and Dr. R. R. Ramsey for their helpful suggestions from time to time during the progress of the present research which was carried on at Indiana University. The author wishes to thank Assistant Mechanician Mr. Henry Corr and Mechanician Mr. John P. Foley for their assistance in the construction and assembly of apparatus. Also the author's thanks go to Mrs. Anna L. Coleman for secretarial assistance.