

Physics. — *The application of the hot-wire anemometer for the investigation of turbulence of an airstream.* By M. ZIEGLER. (Mededeeling N^o. 20 uit het Laboratorium voor Aero- en Hydrodynamica der Technische Hoogeschool te Delft). ¹⁾ (Communicated by Prof. H. A. KRAMERS).

(Communicated at the meeting of September 27, 1930).

In 1926 some experiments were published concerning the measurement of the velocity fluctuations in an airstream. Making use of hot-wire anemometers with very thin wires, the variations of the air velocity were registered in various cases, and at the same time some observations were made about the correlation between simultaneous variations in different places and also about the correlation between velocity and direction variations, for which purpose a special velocity and directionmeter was constructed.²⁾

The obtained results, however, concerned fluctuations of but fairly low frequencies, as frequencies less than 50 per second only are reproduced properly by the torsion-string galvanometers used for the experiments. It is evident that for an exact study of the structure of a turbulent airstream one ought to be able to record fluctuations of much shorter periods.

It was not difficult to replace the torsion-string galvanometers by more rapid oscillographs. With SIEMENS and HALSKE oscillograph systems of the sensitive type, which are suitable for frequencies up till 1500 per., a very short and thin wire (Plat.-Ir., diam. 0,015 mm, length 2 mm), placed in the turbulent boundary layer along a smooth plate and connected with a convenient Wheatstone bridge arrangement, produces variations of current of sufficient amplitude for obtaining good records. An amplifier makes it possible to reach 10.000 periods per sec. with more rapid, but less sensitive systems. A cathode ray oscillograph would enable recording of still higher frequencies without difficulty.

The question remains, however, whether the used hot-wires themselves can give an exact reproduction of the velocity fluctuations in a certain place.

¹⁾ Mededeelingen N^o. 17, 18, 19 are published respectively in the Proc. of the 3rd Intern. Congress for Technical Mechanics (Stockholm), in the Zeitschr. f. angew. Math. u. Mech. 10, p. 326, 1930, and in the Proc. of the 5th Intern. Air Congress (The Hague).

²⁾ Comp. J. M. BURGERS, these Proceedings 29, p. 547, 1926 and Journal of Applied Physics (Moscow), 4, p. 3, 1927. In the latter paper have been reproduced some records of the velocity fluctuations in the boundary layer along a glass plate.

Mentioning must be made also of a series of papers by E. HUGUENARD, A. MAGNAN et A. PLANIOL, Sur une méthode de mesure de la vitesse et de la direction instantanées du vent, La Technique Aéronautique 1923, 1924.

It is difficult to determine how much the wire and its holder can change the local structure of the stream. Only an experimental study of the influence of a small disturbing body on the structure of the turbulent boundary layer can give certainty in this matter. The wires used, however, are so thin and the needles to which they are attached have such a small diameter, that one may suppose that the disturbing effect of the whole instrument can be felt behind the hot-wire only.

For an exact reproduction of the fluctuations in a certain place the length of the wire ought to be small compared to the "wave-length" of the "eddies" in a direction parallel to the wire. A preliminary research accomplished in this laboratory in the beginning of this year, showed that for a study of the eddying boundary layer the hot-wires must certainly be much shorter than the wires used till now. From the fact that in the case of a wire of 0,015 mm diam., placed perpendicularly to the stream in the turbulent boundary layer along a smooth plate, two adjacent parts, each about 2 mm long, could be influenced quite differently, and that the differences were approximately of the same magnitude as the recorded air velocity fluctuations themselves, one may conclude that a hot-wire for such experiments must probably be much shorter than 1 mm.

The records then obtained showed at the same time that velocity fluctuations of fairly high frequency were still reproduced. Hence it was necessary to investigate how much the sensitivity of the hot-wires used diminished for these high frequencies, in comparison to the sensitivity for a constant variation of the airspeed.

In the publication mentioned it was calculated that the lag of a hot-wire for speed variations is given by the equation:

$$\frac{d\theta}{dt} = \lambda(\theta - \theta') \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where λ is a factor the approximate expression of which is:

$$\lambda = \frac{0,24 i^2 R_0}{C\theta} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

(θ = actual temperature of the wire; θ' = equilibrium temperature; i = electric current through the wire; R_0 = electrical resistance at the temperature of the air; C = heat capacity). From equation (1) the loss of sensitivity for sinusoidal speed variations as a function of the frequency can be deduced easily. When a constant airspeed variation produces a variation of the wire resistance equal to A , the amplitude of the periodical resistance variations caused by small sinusoidal velocity fluctuations of amplitude A and frequency f is equal to:

$$a = \frac{A}{\sqrt{1 + (2\pi f/\lambda)^2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

In the formula for the time constant λ of a hot-wire some quantities occur, which generally are known with but very little accuracy. The resistance coefficient, necessary for the determination of the temperature of the wire, depends very much on the composition of the metal, on its structure, on internal tensions etc. The diameter of such thin wires is exactly known only after a special measurement. It is therefore desirable to determine the sensitivity of a hot-wire anemometer for rapid air speed fluctuations by an empirical method.

Until now such an experimental determination has been done only for fluctuations of frequency lower than 60 per sec. and for wires of no smaller diameter than 0,017 mm.¹⁾ In a steady airstream of constant velocity a wire was oscillated mechanically parallel to the direction of the stream. The sinusoidal airspeed variations thus obtained produced periodical resistance variations which were recorded.

For higher frequencies and wires of 0,003 mm diameter for example this method cannot be applied. On the other hand it seems to be very difficult, in an airstream of some velocity, to produce rapid sinusoidal speed fluctuations of known and not too small amplitude.

There exists, however, a quite different method to determine empirically the sensitivity of a hot-wire for rapid fluctuations. Indeed, when instead of periodically changing the velocity of the airstream in which the hot-wire is placed, the electric current which heats the wire is subjected to sinusoidal periodic variations of a given amplitude, the variations of the temperature and thus also of the resistance of the wire will decrease with the frequency in quite the same way as in the case of the resistance fluctuations caused by airspeed fluctuations. Upon this principle the following method of measurement has been based.

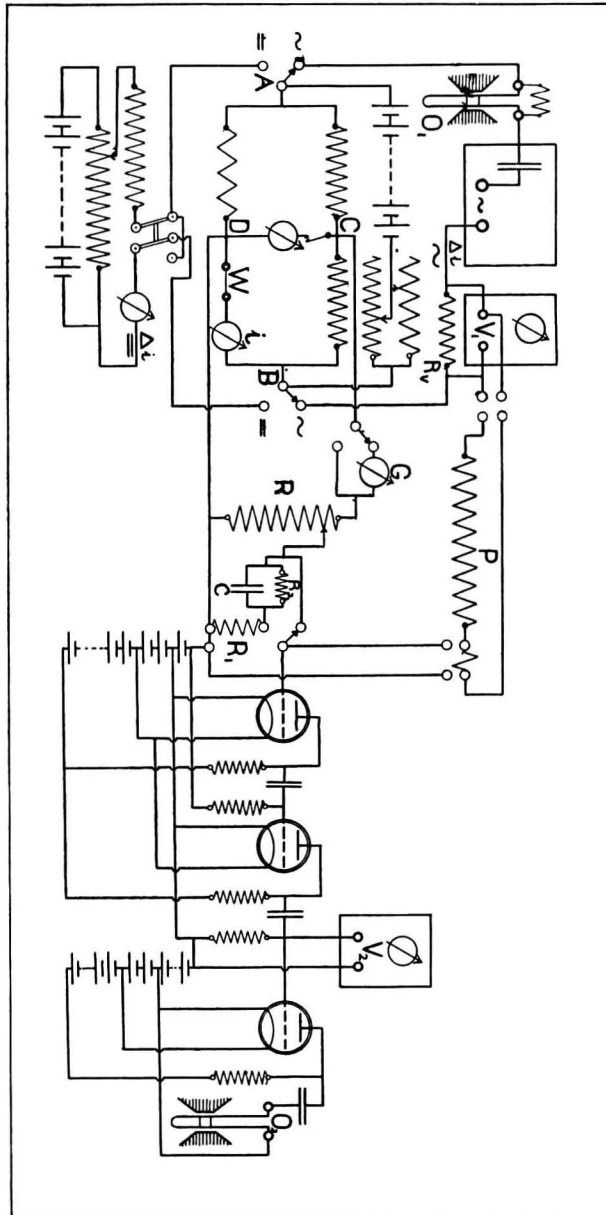
A hot-wire W forms one of the branches of a Wheatstone bridge arrangement (see wiring diagram of the arrangement, fig. 1). The wire itself is mounted in the smaller windchannel of the laboratory and is connected by an electric line with the room where all the measurements were performed. The bridge is balanced for a given air speed and a given heating current. On the direct tension between A and B an alternating tension is superposed, and so a current of sinusoidally varying intensity flows through the branches of the bridge and thus through the wire. If the wire had a constant resistance the balance of the bridge would not be disturbed,²⁾ but as its resistance changes periodically with the current, an alternating tension will be produced between C and D . The value of this alternating tension is proportional to the variation of resistance and thus depends on the frequency in the way indicated above.

¹⁾ See H. L. DRYDEN and A. M. KUETHE, The measurement of fluctuations of air speed by the hot-wire anemometer, Report N^o. 320 N. A. C. A. (Washington 1929). The symbol M used by these authors corresponds to $1/\lambda$.

²⁾ The capacity of the long wire line caused a small difference for high frequencies but this influence was negligible under the conditions of operation.

For the measurements of the amplitude of the alternating current, triode voltmeters were used. These instruments have the advantage above

Fig. 1. Wiring diagram of the arrangement.



thermocouple instruments that they can withstand great potential differences without any danger; besides they permit a better measurement of small currents, as the deflection does not depend on the square of the amplitude but, at least for the used instruments, is approximately a linear

function of it.¹⁾ The alternating tensions between the points *C* and *D*, however, were much too small for direct measurement; hence a two-stage amplifier (amplification 300 times) was necessary. The amplifier is of the ordinary resistance coupled type, but the values of the resistances and capacities are so high, that alternating tensions of very low frequencies (a few periods per second) are still properly reproduced. The application of a real direct current amplifier has many disadvantages when a greater number of stages must be used; therefore a quasi-direct current amplifier is to be preferred.

The source of alternating current is a low-frequency generator, constructed by the N. V. Nederlandsche Instrumentenfabriek „Waldorp” of the type which is universally used now for radio and other purposes.²⁾ The instrument is composed of two high-frequent generators (reaction triode oscillators); one of them produces oscillations of a constant frequency, while the frequency of the other can be varied by means of a variable condensor in such a way that the frequency difference between the two generators can change from 0 to 15000. When both oscillations are superposed, the beats after detection give an alternating current of audible frequency which is practically sinusoidal for a period number higher than 20 if the set is judiciously constructed and used. The apparatus contains an amplifier and the energy of the produced alternating current is about $1\frac{1}{2}$ watts. The amplitude is approximately constant over the whole range and can be adjusted to a given value by means of a volume control.

An oscillograph always was working during the experiments. On the rotating mirror the form of the produced alternating current could be observed; a comparison with the 50 period alternating current of the main circuit of the laboratory made it easy to adjust the exact frequency.

The amplification of the amplifier was determined very often during the experiments by measuring the alternating tension at the end of the second stage, caused by an input tension of known amplitude which was obtained with the potentiometer arrangement *P* indicated in the wiring diagram. In order to eliminate at once all possible errors caused by any frequency dependance of the whole arrangement (bridge, amplifier, etc.), the wire was replaced by a constant resistance, while the bridge was desequilibrated so much that when the normal alternating tension was put between *A* and *B*, the output tension of the amplifier had about the same value as when working with a hot-wire. For a variable frequency and constant tension on the bridge, the variation of output tension then was noted. The amplifier characteristic caused a small decrease of the amplitude for the highest frequencies. Only in a few cases this had to be taken into consideration.

¹⁾ The meters used were 2-Volt Moullinmeters, constructed by the N.V. Nederlandsche Instrumentenfabriek „Waldorp”.

²⁾ See e.g. Y. B. F. J. GROENEVELD, *Physica* 8, p. 157, 1928.

Frequency calibration of a wire.

First the resistance R_0 of the wire at room temperature was determined, by equilibrating the bridge for a very small direct current. Then at the desired airspeed V the heating current i was brought to such a value that the wire had a given resistance R_w . The bridge then was balanced. The intensity of the alternating current is determined with the aid of one of the triode voltmeters, by measuring the tension on a resistance R_v ; at all frequencies this tension is kept at the same value by means of the volume-control. In order to increase the range of exact reading of the output voltmeter, the potential differences which arise are diminished so much with the potentiometer R , that the outputmeter never marks more than 1 volt, which also gives certainty of linear working of the amplifier. As long as the tensions are great enough, the position of the calibrated potentiometer is read for an output tension of 1 volt; when the tensions are lower the voltmeter itself must be read.

In this way the amplitude of the resistance variations caused by alternating currents of frequencies from 25 upwards was measured in various circumstances. In order to get the whole frequency curve it was necessary also to measure the sensitivity for a direct current variation. For this the arrangement shown in the lower left hand corner in the wiring diagram is used. This arrangement makes it possible to read very exactly small variations of the current i comparable with the amplitude of the alternating current which was first superposed. As the used amplifier is not a real direct current one, it was not possible to measure the output tension caused by direct current variations; therefore by means of the microammeter G the current through the resistance R was determined and thus the potential difference between C and D became known. This tension, multiplied by the factor of amplification, gives a value which is comparable with the output tensions got with alternating currents.¹⁾

The fluctuations of the resistance of the wires caused by the airspeed variations in the undisturbed stream of the wind channel in these experiments generally could be neglected against the resistance fluctuations imposed by the alternating current.

This arrangement proved to work very satisfactory. The measurements were repeated more than once and the obtained values generally differed but very little. The origin of the small differences has to be searched rather in the fact, that the simultaneous readings by one operator of various instruments which could not be placed near each other, not always happened with the greatest exactitude, than in an inconstancy of the arrangement.

¹⁾ Of course, those alternating tensions are intended, which should be obtained without the reduction of the input tension by means of the potentiometer R .

When greater differences were found, a change in the hot-wire itself proved to be the cause. One must not wonder indeed that after being heated to a high temperature during a long time the internal properties of the metal and hence the resistance-coefficient, could change sensibly. Moreover the wires of 0,015 mm were attached to their holders with ordinary soft solder, and in some cases this method proved to be not an ideal one: the resistance of the junctures was not always negligible, nor was it constant (this has been remarked also by other investigators). However, when the soldering was done very carefully under the microscope, this inconvenience proved to be redressed.¹⁾

The measurements have been done principally with platinum-iridium wires of 0,015 mm diameter. At first it was investigated whether the amplitude of the superposed alternating current had any influence on the form of

TABLE I.

Frequency	$i = 0.162 \text{ A.}$		$i = 0.234 \text{ A.}$		$i = 0.138 \text{ A.}$	
	$i = 8.75 \text{ mA.}$	$i = 17.50 \text{ mA.}$	$i = 8.75 \text{ mA.}$	$i = 17.50 \text{ mA.}$	$i = 8.75 \text{ mA.}$	$i = 17.50 \text{ mA.}$
0	1.000	1.000	1.000	1.000	1.000	1.000
25	0.735	0.738	0.747	0.764	0.722	0.724
50	0.518	0.497	0.490	0.493	0.515	0.517
100	0.294	0.296	0.321	0.293	0.313	0.300
150	0.203	0.212	0.210	0.201	0.202	0.208
200	0.149	0.153	0.161	0.148	0.148	0.151
300	0.101	0.105	0.101	0.101	0.103	0.099
400	0.073	0.073	0.071	0.072	0.079	0.075
500	0.059	0.060	0.060	0.060	0.062	0.058
700	0.044	0.043	0.047	0.045	0.047	0.044
1000	0.029	0.027	0.031	0.027	0.030	0.029
1500	0.015	0.016	0.021	0.018	0.015	0.017
2000	0.010	0.009	0.017	0.013		
3000			0.013	0.009		

Decrease of amplitude of resistance variations as function of the frequency, determined for a 0.015 mm wire, with superposed alternating currents of 8.75 and 17.50 mA and various heating currents.

¹⁾ See H. L. DRYDEN and A. M. KUETHE, Effect of turbulence in wind tunnel measurements, Appendix, Report N^o. 342 N. A. C. A. (Washington 1929), where these authors describe another solution of the inconvenience mentioned.

the frequency characteristic of the measured resistance variations, and whether the amplitude ought not to be much smaller than was desirable for a convenient reading of the instruments. Therefore measurements were done with alternating currents of effective strength of 8,75 and 17,50 mA. The current which flowed through the wire itself was somewhat smaller, as can be calculated from the way of connection. The results (see Table I) show very clearly that the differences can be ascribed to errors of reading, and do not influence the form of the characteristic curve.

The wire which was used for these measurements, was broken before its length was measured exactly; so the theoretical values cannot be given for comparison.

For the later measurements on wires of 0,015 mm diameter with the same arrangement the effective value of the used alternating current was mostly 8,75 mA.

With the aid of formula (3) the theoretical values were calculated for some frequencies. As $\epsilon = (R - R_0)/\alpha R_0$, where α is the temperature

TABLE II.

Frequency	A		B		C		D		E		F	
	M	C	M	C	M	C	M	C	M	C	M	C
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
25	0.817	0.816	0.773	0.773	0.855	0.855	0.750	0.750	0.690	0.675	0.420	0.340
50	0.556	0.579	0.524	0.520	0.684	0.633	0.518	0.495	0.463	0.417	0.236	0.178
100	0.317	0.336	0.303	0.293	0.443	0.379	0.314	0.274	0.257	0.223	0.130	0.090
150	0.201		0.204		0.311		0.211		0.175		0.084	
200	0.159	0.175	0.163	0.151	0.236	0.201	0.157	0.141	0.128	0.114	0.063	0.045
300	0.101		0.111		0.160		0.107		0.083		0.043	
400	0.083		0.080		0.120		0.081		0.065		0.032	
500	0.067	0.071	0.063	0.061	0.097	0.080	0.063	0.057	0.050	0.046	0.026	0.018
700	0.050		0.047		0.073		0.050		0.039		0.021	
1000	0.029		0.032		0.052		0.035		0.027		0.015	
1500	0.014		0.024		0.036		0.022		0.016		0.009	
2000			0.019		0.027		0.019		0.014		0.007	
3000			0.013		0.019		0.013		0.009			

Decrease of amplitude of resistance variations for a 0.015 mm wire. $R_0 = 31.6$ ohms; length = 2.88 cm. *M*: measured values; *C*: calculated values.

TABEL II (continued).

	Heating current	Resistance	Air velocity	Calculated λ
A	0.146 A.	37.6 Ω	10 m/sec	223
B	0.220 A.	47.6 Ω	10 „	192
C	0.325 A.	57.6 Ω	31.2 „	257
D	0.271 A.	57.6 Ω	10 „	177
E	0.244 A.	57.6 Ω	5 „	144
F	0.153 A.	57.6 Ω	0 „	57

coefficient of the resistance, the formula for λ can be transformed into $\lambda = \frac{i^2 a R_0^2}{4,2 C (R - R_0)}$. For a given wire $a R_0^2 / C$ is constant.

In table II the results are given obtained with a platinum-iridium wire of 0,015 mm diameter and 2,88 cm length. (For the resistance coefficient was accepted $\alpha = 0,00093$, a value which had been determined empirically some time ago.)

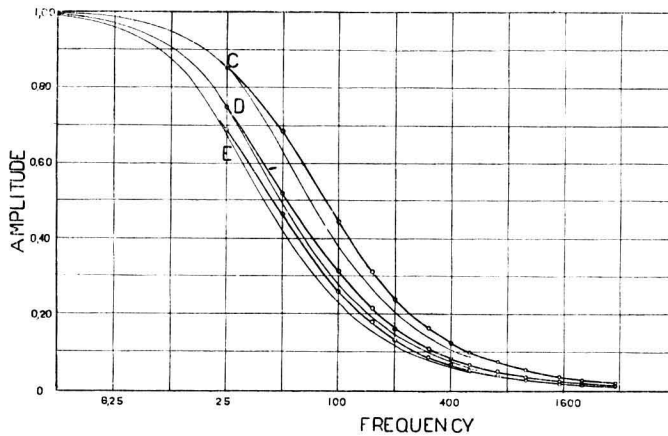


Fig. 2. Graphical representation of the cases C, D and E of table II.

Thick lines: measured values

Thin lines: theoretical curves.

The graphs of figure 2 show the decrease of the amplitude in function of the frequency in three cases, relating to a constant temperature of the wire, and to different airspeeds, thus to different heating currents. The calculated values are indicated by the thin lines. The possible inexactitudes are so many that this result may be considered as fairly satisfactory, both with regard to the developed theory and to the experimental method. Indeed the coefficient of resistance is known with but very small exactitude, the diameter of the wire has been taken simply from

the data supplied by the manufacturing firm; the sensitivity for direct and for alternating current is measured in a different way and with different instruments; the produced alternating current is not entirely free from harmonics. A small error made in the comparison of the two sensitivities causes a rise or a fall of the whole curve, while an error in the value of the calculated λ influences the inclination of the curve. By changing these quantities by amounts which lie wholly within the allowable limits, the curves can be brought to coincidence.

Measurements done with two other wires correspond well with the theory (Table III). The fact that for the lower frequencies in both cases

TABLE III.

Frequency	G		H	
	M	C	M	C
0	1.000	1.000	1.000	1.000
25	0.795	0.812	0.867	0.905
50	0.562	0.573	0.705	0.727
100	0.342	0.330	0.468	0.467
150	0.207		0.334	
200	0.165	0.172	0.248	0.256
300	0.111		0.169	
400	0.095		0.125	
500	0.070	0.070	0.101	0.105
700	0.047		0.072	
1000	0.030		0.049	
1500	0.016		0.032	
2000			0.023	
3000			0.017	

Decrease of amplitude of resistance variations as function of the frequency for two 0.015 mm wires.

M = Measured, C = Calculated.

G: length = 2.08 cm; heating current = 0.138 A.; $R = 27.6$ ohms; velocity of the air = ca 10 m/sec. Calculated $\lambda = 219$.

H: length = 2.48 cm; heating current = 0.164 A.; $R = 31.6$ ohms; velocity of the air = ca 34 m/sec. Calculated $\lambda = 331$.

a smaller value is found than the calculated one, can be ascribed to the circumstance that the alternating currents of low frequency obtained from the generator have a comparatively greater percentage of harmonics than the currents of higher frequency.

Measurements on wires of smaller diameter.

In the same way measurements have been done with platinum wires of 0,003 mm diameter. Of course very much patience is needed for experimenting with such thin wires, as ruptures are very frequent. For the study of the turbulent boundary layer it will be necessary, however, to use them. As has been remarked already, the wires must be very short, and the variations of tension caused by fluctuations of air speed of a given amplitude are greater on a thin wire with a high resistance, than on a thicker wire of the same length. It is desirable also to have a wire diameter which is very small compared to the length for eliminating as much as possible the disturbing cooling effects of the ends. When such thin wires are used the ends of the holders can be made very thin, and the perturbation of the air stream can be reduced to a minimum. The characteristic curve for thin wires of course is much more advantageous than for wires of 0,015 mm diameter, as is demonstrated by the results mentioned below. When a compensative circuit is used as described further in this communication, the sensitivity of the whole anemometer remains much greater when the same frequency characteristic is required.

Table IV give some results obtained with wires of 0,003 mm diam. and of lengths from 5,5 to 0,75 mm.

TABLE IV.

Frequency	I		J		K	
	M	C	M	C	M	C
0		1.005		1.004		1.004
50	1.000	1.000	1.000	1.000	1.000	1.000
100	0.956	0.987	0.950	0.989	0.945	0.988
200	0.902		0.792		0.830	
500	0.712		0.700		0.725	
700			0.582		0.574	
1000	0.510	0.471	0.457	0.503	0.448	0.490
1500	0.372		0.315		0.344	
2000	0.316	0.261	0.250	0.278	0.270	0.271
3000	0.218		0.166		0.180	
5000	0.129	0.107	0.097	0.115	0.104	0.111
7000	0.098		0.067		0.071	
10.000	0.066	0.054	0.044	0.058	0.040	0.056

Decrease of amplitude of resistance variations as function of the frequency for 3 wires of 0.003 mm diameter.

TABLE IV (Continued).

	Length	Heating current	R	Calculated λ
I	5.50 mm	0.022 A.	269.5 ohms	3390
J	0.90 mm	0.027 A.	21.1 ohms	3640
K	0.75 mm	0.026 A.	18.6 ohms	3510

Velocity of the air = ca 10 m/sec.

As accurate values for the direct current sensitivity were not available, the sensitivity for 50 periods per sec. has been taken equal to 1. The differences between observed and calculated values are greater than for wires of 0,015 mm; but of course the possible errors are much greater in the case of thinner wires. For the resistance coefficient here 0,0038 was accepted.

Compensating circuit.

When an exact reproduction of airspeed fluctuations is wanted, fluctuations of high frequency must be reproduced in the same proportion as slow fluctuations. With a simple compensating circuit it is possible to make the characteristic curve of a wire horizontal up till an arbitrary high frequency. Of course the use of such a circuit causes a diminution of sensitivity for low frequencies.

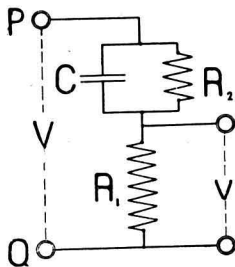


Fig. 3.

Compensating circuit.

When in the circuit of fig. 3 between P and Q an alternating tension is applied of frequency $f = \omega/2\pi$ and amplitude V , the tension v will be equal to:

$$v = V \sqrt{\frac{R_2^2 + R_1^2 R_2^2 \omega^2 C^2}{(R_1 + R_2)^2 + R_1^2 R_2^2 \omega^2 C^2}} \quad (4)$$

At the frequency 0 (direct tension): $v = VR_2/(R_1 + R_2)$, and thus a constant variation of V with ΔV causes a variation $\Delta v = \Delta VR_2/(R_1 + R_2)$. At the frequency $f = \infty$: $v = V$.

If such a circuit is placed in the arrangement of the hot-wire anemometer, it is not difficult for a given value of C to determine experimentally the values which R_1 and R_2 must have in order to get an approximately horizontal characteristic curve up till a given frequency. The value of R_1 must be chosen in such a way, that for $R_2 = \infty$ at a desired high frequency now a maximum of amplitude occurs. Then R_2 must get such a value that the lowest frequencies are reproduced with the same sensitivity.

With the arrangement used it thus is possible not only to determine the normal characteristic curve of a wire within very short time, but it is also possible to make the sensitivity constant over a given range of frequencies.

Fig. 4 gives in Volts the effective output tension of the amplifier for a wire of 0,015 mm and for a wire of 0,003 mm, both without and with compensation (the input tension is kept constant in every case). For a better comparison the compensated characteristic is given also on

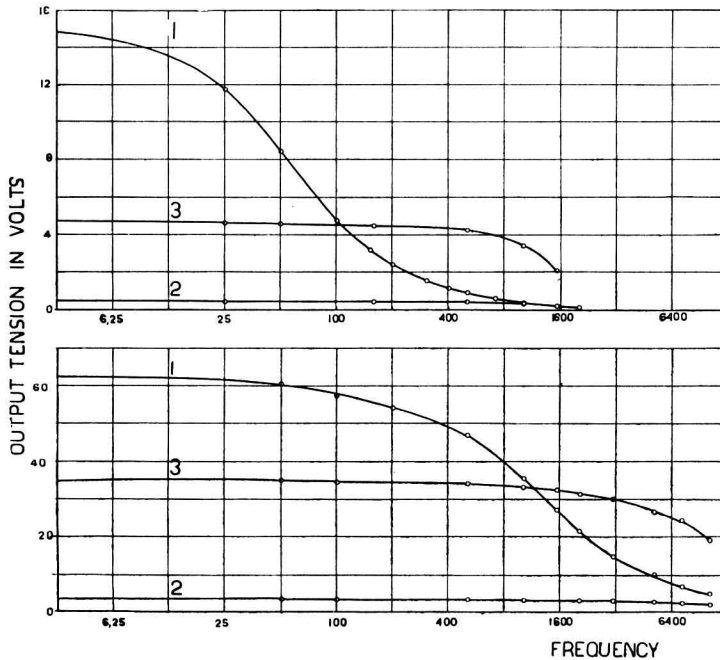


Fig. 4. Characteristic curves of a 0.015 mm wire (upper diagram) and a 0.003 mm wire (lower diagram), without and with compensation.

1. Normal curve;
2. Compensated curve on the same scale;
3. Compensated curve on an enlarged scale ($10\times$).

a greater scale. It may be remarked that the degree of compensation is wholly arbitrary, and that the requirements will depend in general on the circumstances and the results of the experiments themselves.

Experiments executed just now with a compensated hot-wire of 0,003 mm diam. and 0,75 mm length, which satisfied the requirements of sufficient sensitivity for high frequencies, have demonstrated the existence in the turbulent boundary layer of velocity fluctuations with periods of the order of $1/1000^{\text{th}}$ of a second. Records obtained with a high velocity of the paper in the photographic camera showed fluctuations with frequencies above 1000 (the oscillograph systems used in these experiments do not allow to record fluctuations with periods much above 1500). In the diagram fig. 1 the third amplifying stage, necessary for obtaining records with the oscillograph system O_2 , has been indicated at the right hand side.

In this paper we have considered only the amplitude of the fluctuations reproduced by the hot-wire arrangement. Investigations are in progress concerning the change of phase which the fluctuations undergo. The phases are of importance f.i. in the correct reproduction of the complicated fluctuations of the velocity which usually occur, and which are not at all simply harmonic.¹⁾

We feel obliged finally to point to the rather preliminary character of the whole arrangement, which has been constructed principally in view of determining the characteristic curve. A description of an arrangement made especially for the investigation of fast fluctuations of the air velocity we hope to publish before long, together with some results obtained with it.

¹⁾ Note added in the proof. The use of the compensating circuit greatly reduces the change of phase, due to the lag of the wire.
