SPECTRAL ANALYSIS APPLICATION IN HOT-WIRE ANEMOMETER INVESTIGATIONS OF PHENOMENA APPEARING IN VORTEX FLOW METER

G.L. Pankanin[1], J. Berlinski[2], R. Chmielewski[3]

[1]Institute of Electronic Systems, Warsaw University of Technology, Warsaw, Poland, e-mail: g.pankanin@ise.pw.edu.pl
[2]Institute of Electronic Systems, Warsaw University of Technology, Warsaw, Poland, e-mail: jberl@ise.pw.edu.pl
[3]Institute of Electronic Systems, Warsaw University of Technology, Warsaw, Poland, e-mail: rch227@ise.pw.edu.pl

Abstract: Investigations of phenomena appearing in the vortex meter are considered in the paper. The hot-wire anemometer system has been used in the laboratory tests. Informations yielded due to spectral analysis of measuring signal facilitate interpretation of test results obtained in experiments and hence better understanding of phenomena is feasible. Results of laboratory investigations carried out on the measuring stand are presented.

Keywords: Karman vortex street, hot-wire anemometer, vortex flow meter.

1. INTRODUCTION

The vortex meter design is based, as it is well-known, on the generation of the Karman vortex street on the obstacle placed inside the flowing fluid. The frequency of generated vortices is nearly the linear function of the flow velocity:

$$\mathbf{f = S_T \cdot \frac{v}{d}} \qquad (1)$$

where:

    v – flow velocity
    d - characteristic dimension of the bluff body
    S_T – Strouhal number

In spite of hundreds of papers and articles published during last three decades concerning the vortex meter design, the phenomena occurring in the vortex meter are not completely recognized yet. Common meter properties are known, like independence of the physical parameters of the fluid on the vortex frequency. Also, no moving parts in the system ensures very high reliability.

The conclusion taken from the literature and the authors' own experience is that complete description of the phenomena appearing in the vortex meter is very difficult. Hence the idea formulated by the first author of this paper in [1] that the comprehensive recognition should be only made by using various research methods. Analysis of the measured signal, hot-wire anemometer investigations of the flow field, flow visualization with image processing and numerical modelling have been mentioned in the paper as preferred research methods. Partial information concerning the

phenomena properties yielded due to various methods application should make up the coherent picture of the vortex shedding. Results obtained due to the application of different methods may also constitute the confirmation of correctness of carried out investigations and formulated conclusions. The methods of investigations of the phenomena arising in the vortex meter are described in [2].

The hot-wire anemometer measurements were used in the articles concerned the vortex meter from the very beginning. Due to its simple structure and easiness of manufacturing, in the first designs the hot-wire often was used as a sensor. Unfortunately, very low reliability of such devices has caused the necessity of looking for other solutions. Hence the variety of sensors used in experiments like pressure sensors or the sensors based on application of the ultrasonic waves [3-9].

It is surprising, that in subsequent papers the hot-wire probe has been rather rarely used. The most significant investigations carried out with the hot-wire application are reported in [10, 11]. Terao et al. concluded, that the vortices created on the bluff body located in the pipe are much stronger than in a free stream. It confirms the stabilizing role of the pipe walls in the vortex shedding. Meaningful investigations were carried out towards verification of formulated by von Karman [12] hypothesis that the ratio of transverse spacing of vortices to streamwise spacing is 0.281. Terao et al. have found that in the pipe this value is 0.11 [11]. Also works [1, 13] show, that valuable and useful knowledge concerned the Karman vortex street phenomenon can be gained due to the method based on the hot-wire anemometer application.

In this paper, the authors would like to show the new feasibilities of investigations carried out with application of the hot-wire anemometer.

2. PURPOSE

The presented investigations were aimed for further recognition of the Karman vortex street. It is of the great importance from the point of view of the vortex meter design optimization. It was already underlined, that the Karman vortex street phenomenon must be investigated using various methods. Comprehensive approach to this

issue relies on mutual completion and verification of yielded results.

Investigations carried out with the hot-wire anemometer application enable determination of fluid velocity for current probe location. In case of movable hot-wire probe, the whole area of the Karman vortex street appearance can be tested. So the velocity distribution downstream the bluff body can be completely determined.

Problems with interpretation of results obtained from the hot-wire probe have forced the authors to look for additional sources of information concerned the phenomena. It was stated, that the spectral analysis of measuring signals can enable considerable widening of the knowledge. Due to graphs presenting the changeability of the power spectral density distribution for various hot-wire probe locations deeper conclusions can be formulated.

3. METHODS

The hot-wire anemometer is applied usually for determination of the temporary value of flow velocity at a given point of space. In the area of the Karman vortex street appearance, various velocity components are observed. Hence the problems with interpretation of obtained results are understandable.

It is even much more complicated because the areas of various properties downstream the bluff body can be found e.g. the stagnation region is characterized by low fluid flow velocities caused by the bluff body shadow. On the other hand, the steady velocity area is characterized by dominant axial fluid velocity. Hence it should be underlined that the area of the fluid velocity vectors is divertisied. It was stated that such flow area can be described by mean values of the velocity vectors and the RMS values of alternating components. Mean flow velocity is described as follows:

$$v_{mean} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \vec{v}(t) dt \qquad (2)$$

and turbulence τ:

$$\tau = \sqrt{\frac{1}{2 \cdot \Delta t} \int_{t-\Delta t}^{t+\Delta t} [v_\tau(t)]^2 dt} \qquad (3)$$

where:

$$\vec{v}_\tau(t) = \vec{v}(t) - \vec{v}_{mean} \qquad (4)$$

Laboratory tests were carried out on measuring stand for gas flow meters calibration (D=40mm) presented in Fig.1. The proper flow rate value is set by the special flap driven by the stepped motor. Due to the application of specially designed module (Fig.2), the investigations with mobile hot-wire probe were possible. The hot-wire probe carrier can be moved along two axes. Hence scanning of the whole flow velocity area is ensured.

For the application of spectral analysis the probe stepped movement with 1-mm steps downstream the bluff body along the pipe axis has been used. The tests have relied on measuring of two velocity components: axial and transverse. For each probe location, the signals from the both wires have been processed and transformed (using FFT algorithm) into the power spectral density distribution. Finally, the power spectral density distributions for both velocity components have been attained.
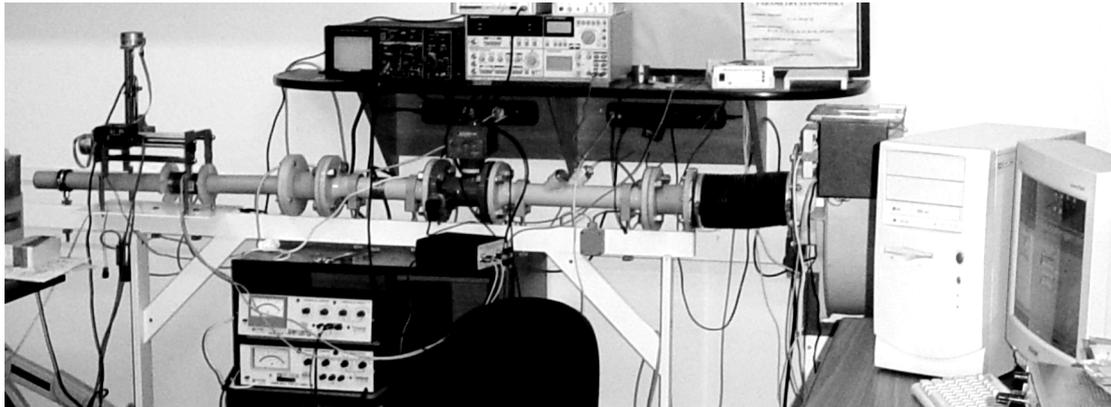

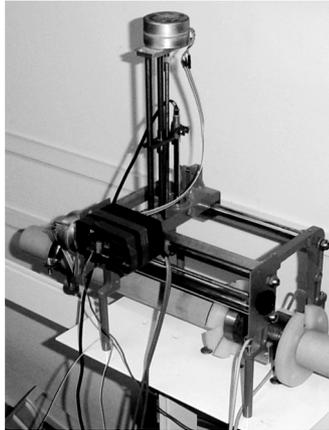**Fig.1. Measuring stand for gas flow meters calibration**

Fig.2. Module for hot-wire probe movement

The stand ensures also the possibility of observation of flow velocity signals in the chosen probe location. The spectral power density distribution for both velocity components in chosen probe location can be observed as well.
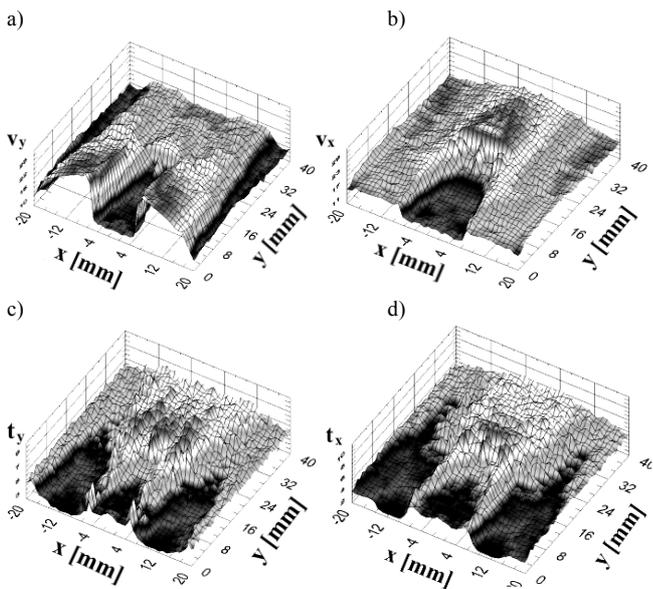
4. RESULTS AND DISCUSSION

Fig.3. Velocity and turbulence distributions in axial plane perpendicular to circular cylinder bluff body (a&c - axial, b&d – transverse)

Results of the investigations of flow velocity area downstream the bluff body are shown in Figs.3&4. Results for circular cylinder - presented in Fig.3. show, that in the closest neighbourhood of the bluff body the area of velocity "silence" is observed, where both velocity components as well as both turbulences are very low. At the end of this region more intensive disturbances are observed. It suggests the occurrence of the vortices. Unfortunately it is seen that they rapidly decay. It means that vortices generated on the circular cylinder are not very stable. In the case of the bluff body with the slit (Fig.4.) the situation becomes completely different. Regular and wide areas of increased mean velocity and turbulence are observed. Comparing the graphs from Fig.3. and Fig. 4. we can conclude that existence of the slit in the bluff body causes considerable changes in the flow velocity and turbulence distributions.
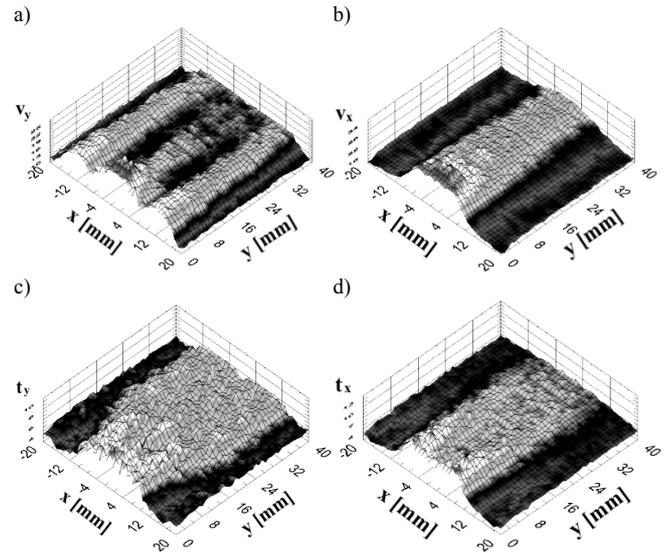

Fig.4. Velocity and turbulence distributions in axial plane perpendicular to circular cylinder with slit as bluff body (a&c – axial, b&d – transverse)

In the case of the Karman vortex street occurrence the local increase of mean velocity and especially the increase of turbulence can be associated with velocity disturbances. The problem is to identify them as related to the Karman vortices. As it is well-known, the Karman vortices are characterized by stable frequency. Hence the idea of application of spectral analysis of the signals from the hot-wire probe.
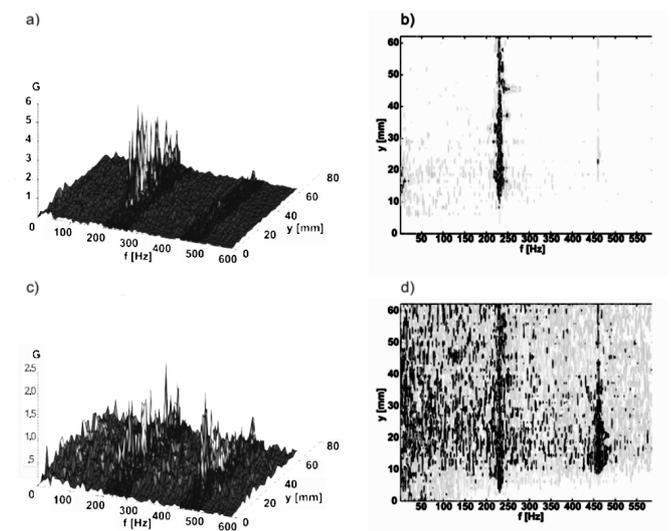

Fig. 5. Power spectral density distribution of velocity components for circular cylinder of 10 mm diameter: a&b – for axial velocity, c&d – for transverse velocity

On the basis of the graphs presented in Fig.5. obtained for axial displacement of the probe downstream the bluff body it can be confirmed, that in its close neighbourhood, the

signal of the vortex frequency decays. It is consistent with the graphs shown in Fig.3. and it once again confirms the thesis of the "stagnation region" existence, explained by Birkhoff [14]. It is also remarkable, that for this bluff body, the main spectral line is dispersed and considerable amount of noise is noticed. The slit existence in the bluff body causes considerable changes in its performance (Fig.6.). The power spectral density distribution has much higher signal-to-noise ratio and the power density line for the Strouhal frequency is better distinguished. This line also appears in the close neighbourhood of the bluff body. In the plots obtained for transverse velocity, the distinct component of double of the vortex signal frequency is visible. It can be explained by the "full bridge rectifier" effect, which results from the fact that the sense of velocity vector is not distinguishable by the hot-wire probe. Additionally, very interesting phenomenon has been observed. Slight frequency shift of the vortex signal in the close neighbourhood of the bluff body was found. It may be explained by the fact, that the probe insertion into the region of vortices creation can disturb the phenomenon. We have shown that the vortex shedding phenomenon is extremely sensitive to disturbances in the close neighbourhood of the bluff body.
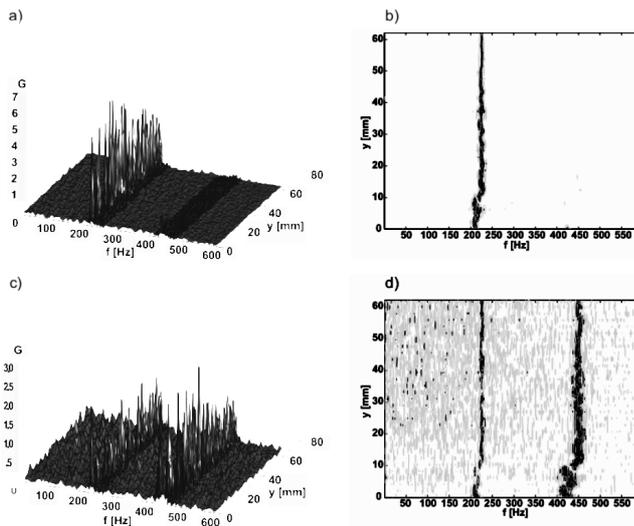

Fig. 6. Power spectral density distribution of velocity components for circular cylinder of 10 mm diameter with slit: a&b – for axial velocity, c&d – for transverse velocity

Power spectral density distributions of the axial velocity for the probe located in pipe axis in various distances **y** from the back side of the bluff body are shown in Fig.7. It is easy to notice that the main spectral line (related to the vortex frequency) is clearly distinguishable for each tested probe location. Considerable differences, however, can be observed. The highest vortex energy has been found for y=10 mm. For smaller and greater **y**-values the vortex energy becomes lower and flow noises are better visible. The power spectral density distribution for y=0 should be also discussed. The additional spectral line of double vortex frequency is distinguished. It results from the fact, that for this probe location the axial velocity changes its sense and the mentioned earlier the "full bridge rectifier" effect appears.

This effect is better visible on the graphs given in Fig.8. For x≤4mm the double vortex frequency line is clearly distinguishable. It means that the region where the lengthways velocity changes its sense is of considerable area. On the basis of the graphs from Fig.8. it can be noticed that the maximum energy of vortices is found outside the pipe axis (in our case for x=6mm). It should be also marked that the vortex frequency can be detected on the whole pipe axis, also near the pipe wall. On the basis of the unpublished here data it can be also noticed that the maximum of the vortex energy along the pipe radius moves towards greater x-values versus the increased distance from the bluff body. It is accompanied, however, by the energy decrease.
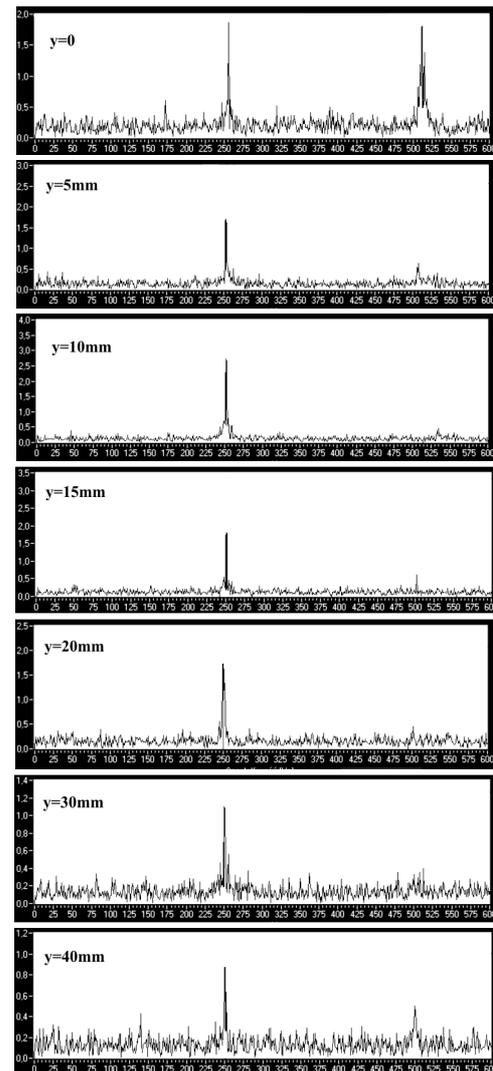

Fig.7. Power spectral density distributions of axial velocity for hot-wire probe located in pipe axis in various distances from the back side of circular cylinder with the slit (φ=13 mm, Q=45 m³/h)

Concluding, it should be underlined, that the tests have confirmed the existence of the specific region close to the bluff body, where the vortices are formed. It should be also underlined, that the optimal sensor position appears downstream the bluff body outside the pipe axis. But the vortex signal, however, appears in the whole area downstream the bluff body.
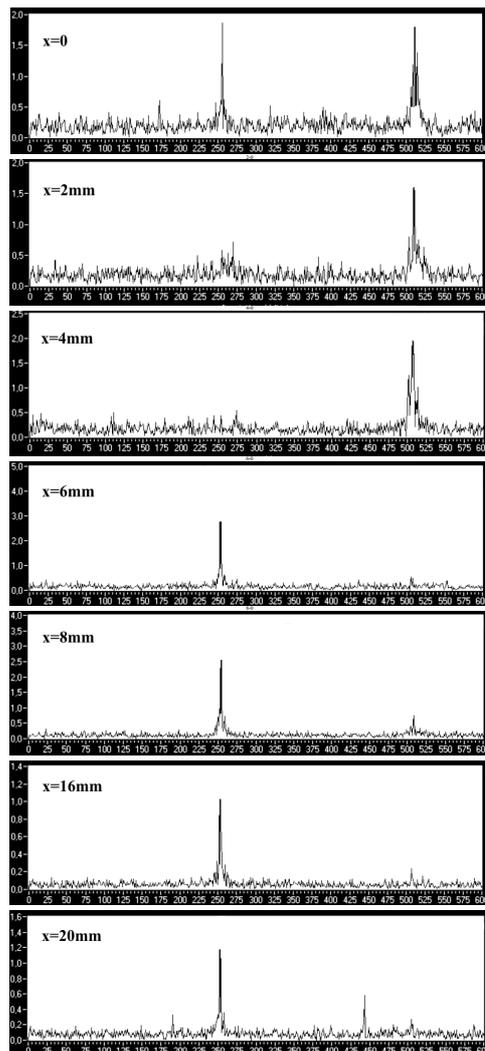
Fig.8. Power spectral density distributions of axial velocity for hot-wire probe located in plane close to back side of circular cylinder with the slit (ϕ=13 mm, Q=45 m³/h) and perpendicular to pipe axis in various distances from the pipe axis

5. CONCLUSIONS

In spite of the easiness, the hot-wire anemometry method enables carrying out investigations providing very valuable and interesting results. On the basis of the graphs presenting the flow velocity and turbulence areas, the common conclusions concerned their distributions in the space can be formulated. Especially such efects like the stagnation region existence and intensity of flow disturbances can be determined. Spectral analysis of the signals obtained from the hot-wire probe enables further phenomena identification. Energy and stability of generated vortices for each chosen point of space downstream the bluff body can be evaluated. Optimal sensor location from the point of view of vortices energy and regularity can be determined. This method also enables discovering of such phenomenon like sensitivity of the region close the bluff body on small mechanical disturbances (like insertion of the hot-wire probe). Due to the tests presented here the knowledge of the stagnation region in the vortex meter has been also widened and earlier hyphotheses have been confirmed. It is also worth to notice, that the realized measuring system appears as very useful tool for investigations of the phenomena occurring in the vortex meter.

REFERENCES

[1]   G.L. Pankanin, J. Berliński, R. Chmielewski, "Karman Vortex Street Visualization", Proc. of International Symposium on Flow Visualization, paper No 239, CD-Rom proceedings, Edinburgh, UK, August 2000.

[2]   G.L. Pankanin, „The vortex flowmeter: various methods of investigating phenomena", Meas. Sci. Technol. 16(2005) R1-R16, March 2005.

[3]   D.J. Lomas, "Vortex flowmetering challenges the accepted techniques", Control & Instrumentation, July/August 1975.

[4]   J. Kopp, O. Soroko, "Liquid vortex shedding flowmeter", Proc. Industry Oriented Conference and Exhibit, Milwaukee, USA, October 1975.

[5]   R.W. Miller, J.P. De Carlo, J.T. Cullen, "A vortex flowmeter – calibration results and application experience", Proc. Flow-Con 1977, Brighton, UK, 1977.

[6]   V. Hans, H. Windorfer, "Comparison of pressure and ultrasound measurements in vortex flow-meters", Measurement 33 (2003), pp. 121-133, 2003.

[7]   V. Hans, C. Filips, "Improving vortex flow metering using ultrasound", Proc. of International Conference of Flow Measurement FLOMEKO 2003, Groningen, The Netherlands, CD-Rom proceedings, May 2003.

[8]   B. Menz, "Vortex flowmeter with enhanced accuracy and reliability by means of sensor fusion and self-validation", Measurement 22 (1997), pp. 123-128, 1997.

[9]   J. Coulthard, Y. Yan, R.P. Keech, "Flow metering by vortex wake transit time measurements", Proc. of International Conference of Flow Measurement FLOMEKO 1993, Seoul, Korea, pp. 581-589, 1993.

[10] Y. Terao, H.M. Choi., M. Takamoto, and G. Matsui, "Measurement of Karman vortex street shed in a circular pipe using triple hot-wire probe", Proceedings of International Conference of Flow Measurement FLOMEKO'98, pp. 197-201, Lund, Sweden, May 1998.

[11] Y. Terao, H.M. Choi., R.B. Edra., M. Takamoto, "An experimental study on flow structure in vortex flowmeters", Proceedings of International Conference of Flow Measurement FLOMEKO'93, pp. 507-514, Seoul, Korea, 1993.

[12] T. von Karman, „Uber den Mechanismus des Widerstandes, den ein bewegter Korper in einer

Flussigkeit erzeugt", Nachr. Ges. Wiss. Gottingen, Math. Phys. Klasse pp. 509-517, 1911.

[13] J. Berliński, R. Chmielewski, G.L. Pankanin, "Vortex Flow Field Investigations with Application of Hot-Wire Anemometer", Proceedings of International Conference of Flow Measurement FLOMEKO 2000, CD-ROM proceedings, Salvador, Brazil, May 2000.

[14] G. Birkhoff, "Formation vortex street", Journal of Applied Physics 24, No 1, pp. 98-103, 1953.