PROCEEDINGS RESEARCH CENTER OF THE PUBLIC INSTITUTION VIBROMECHANIKA

Journal of Vibroengineering

2000 No2 (3)

ISSN 1392-8716

Contents

VILNIUS

I-st INTERNATIONAL ANNIVERSARY CONFERENCE
BALTIC-ACOUSTIC 2000
17-21 September 2000 *VILNIUS* LITHUANIA

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Peculiarities of Application of the Acoustic Correlation Method for the Gas Pipeline Hermeticity Control

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ABSTRACT: In the energy supply systems and industry it is very important to avoid leakage to the environment of natural gas and other gaseous chemical products. The regular control of hermeticity of these objects is of prime interest. One of more perspective methods of detection of leakage it is an acoustic correlation method.

The present paper describes the peculiarities of application of the acoustic correlation method while hermeticity of the gas pipeline is investigated during exploitation and when the hydraulic tests are fulfilled. The influence of alteration of the gas pressure and temperature on an accuracy of leakage co-ordinates determination is analysed. The modelling of influence of the gas temperature and gas flow velocity on the determination of leakage co-ordinates is carried out. The influence of alteration of these parameters on the accuracy of leakage co-ordinates determination is investigated. The algorithms for determination of leakage co-ordinates in the pipeline with evaluation of the gas flow velocity, gas temperature, pressure and the pipeline diameter are submitted.

KEYWORDS: acoustic correlation method, gas pipeline leakage, sound velocity, gas temperature.

NOTATION

l- length of the measuring section
c- sound speed in the gas
Δt- difference of propagation times
v- gas flow velocity
Q- heat energy
U- internal energy of the gas
T- absolute temperature
R- universal gas constant
γ- ratio of specific heats, c_p/c_v
μ- molar mass
p- gas pressure
ρ- density

1. INTRODUCTION

One of the most perspective methods for detection of leakage of the gas pipeline transporting liquid and gaseous products is an acoustic correlation method [1,2]. It is cheap, effective and reliable [1,2,3]. This method enables one to determine the leakproofness of the pipe section under investigation and to determine the leakage place with accuracy ±0,5m, when the direct acoustic contact of electroacoustical transducers with the gas pipeline is possible only in the ends of the section under investigation [4,5]. It enables to decrease markedly the earthwork volume as well as to diminish expenditure for the uncovering the pipeline when finding the damaged sites of the gas pipeline. An acoustic correlation method might be successfully used when the hydraulic tests are fulfilled and under the normal exploitation conditions. This measuring method is based on the registration of the acoustic noises generated by the leakage and on the determination of correlation of these signals received by the electroacoustical transducers located in the ends of the pipeline under investigation (Fig.1). If there is the leakage in the pipe section under investigation, the noises are generated by the flowing products. As a result of the correlative analysis, the difference (Δt) of propagation times (Δt) of the acoustic signals from the damaged place to the electroacoustical transducers is determined.

The co-ordinate (l_1) from the leakage to the one of transducers is given by an expression [6,7]

$$l_1 = \frac{l - c\Delta t}{2}. \tag{1}$$

Where l is the length of the section under investigation and is the sound speed in the gas filling the pipeline.

The mechanism generation of acoustical noises at the damaged sites of the pipeline transporting liquid or gaseous products is the same. However the energy distribution of the noises generated at the damaged places of the pipeline is different. It depends on the large difference of the relation of the acoustical impedance's of liquids, solid states and gases. When the fluid products are gushing through the hole the greater part of energy of the acoustical noises generated at the leakage place is transferred to the walls of the pipeline [8,9]. Therefore the noises propagating in the walls of the pipeline are registrated when the hermeticity of pipeline transporting fluid products (oil, water or thermal water and etc.) is investigated. On the other hand, the main part of energy of the acoustical noises generated at the damaged pipelines transporting gas (natural gas, steam) remains in the gas media filling the pipeline and is not transferred to the walls of the pipeline [10,11]. Therefore the noises propagating inside the pipeline transporting gas products are registrated when the hermeticity of the pipeline is detected [12].

This property of the pipeline transporting the gaseous products predetermines the possibilities of application of the (1) algorithm:

The Journal was received on 3 July 2000 and was accepted for publication on 30 August 2000.

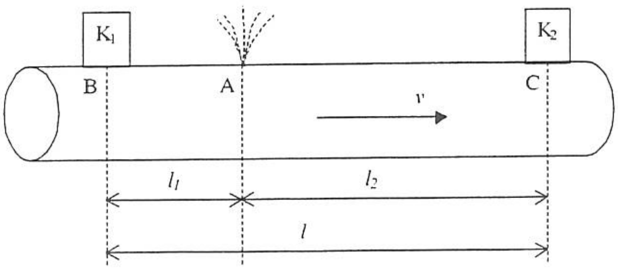

Fig. 1. Block diagram of the system for determination of the leakage in pipeline

1. Because of the gas motion in the pipeline the time intervals during which an acoustical signals (generated by the leakage) reaches the electroacoustical transducers are changed, when the hermeticity of pipeline is detected during an exploitation.
2. When the hermeticity of pipeline is detected by the hydraulic tests, while the pressure in the pipeline is raised, the temperature of the gas inside the pipeline and the speed of sound c are raised too.

The both of these factors influence the accuracy of determination of the leakage co-ordinates in the pipeline.

2. INVESTIGATION

At first, the influence of the gas motions inside the pipeline it will be estimated.

Acoustic noises generated by the leakage (point A) and propagating upstream the gas flow arrive to the receiver located in the point B after the time interval

$$t_1 = \frac{l_1}{c - v}, \tag{2}$$

where v is the gas flow velocity in the pipeline. On the other hand, acoustic noises propagating downstream from the leakage arrive to the receiver located in the point C after the time interval

$$t_2 = \frac{l_2}{c + v}. \tag{3}$$

By using Fig.1 from equations (2) and (3) one can find an algorithm which consider the influence of flow velocity on the determination of leakage co-ordinate l_1^* when the measurements are performed during an exploitation of the gas pipeline

$$l_1^* = \frac{l(c-v) - (c^2 - v^2)\Delta t}{2c}, \tag{4}$$

where $\Delta t = t_2 - t_1$. With the purpose of quantitative evaluation of influence of the gas flow velocity on the accuracy determination of leakage co-ordinates the difference of time Δt it may be expressed from the (4) equation

$$\Delta t = \frac{l(c-v) - 2cl_1^*}{c^2 - v^2}. \tag{5}$$

The discovered value of Δt shows the real difference of propagation times of acoustic noises from the leakage to the location points of ellectroacoustical transducers. The co-ordinates of the leakage might be calculated by using the (1) algorithm when substituting to it the (5) equation

$$l_1 = \frac{lv}{2(c+v)} + \frac{l_1^* c^2}{c^2 - v^2}. \tag{6}$$

By using equations (4) and (6) an absolute deflection $\Delta l = l_1 - l_1^*$ of the leakage place determination may be find out. It appears when the leakproofness of the pipeline transporting gaseous products is investigated by the acoustic correlation method and the gas motion velocity v inside the pipeline is not evaluated.

This deflection may be described by the equation

$$\Delta l = \frac{lv}{2(c+v)} + \frac{l_1^* v^2}{c^2 - v^2}. \tag{7}$$

How one can see from the (7) equation the absolute deflection of the leakage place depends on the two terms. One of them (the first in the right side of the (7) equation) is directly proportional to the length l of the pipeline under investigation and is entirely independent from the co-ordinates of the leakage place. On the other hand, the magnitude of the second term in the right side of the (7) equation depends on the co-ordinates of the leakage, but the influence of length of the pipe section under investigation is negligible.

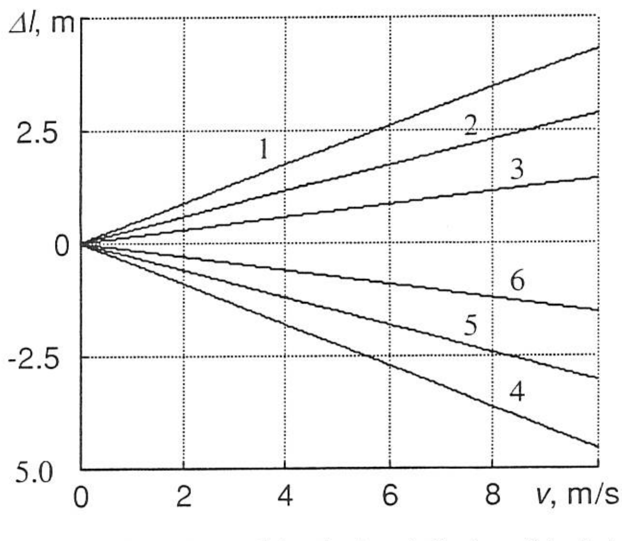

Fig. 2. The dependence of the absolute deflection of the leakage place determination on the flow velocity when the length of the measuring section is: *3* , *6*-100m, *2* , *5*-200m, *1* , *4*-300m.

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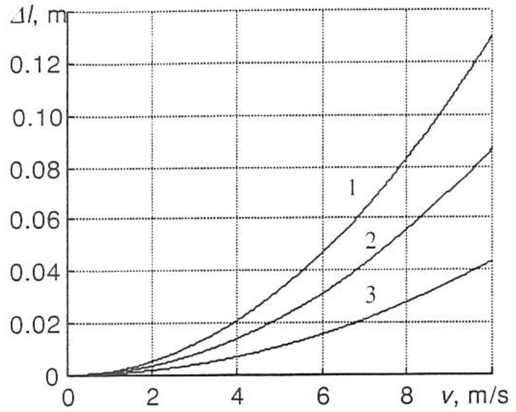

Fig. 3. The dependence of the absolute deflection of the determined leakage place on the flow velocity when the distance from the leakage to the end of the pipeline: *1*-150m, *2*-100m, *3*-50m.

Let us to analyse the influence of these terms for an accuracy of the leakage co-ordinate determination. The length l of the pipeline under investigation usually does not exceed 300m [4,5,12]. At such a way, the maximal distance $l^*_{1\,max}$ from the leakage to the nearest electroacoustical transducer does not exceeds 150m. Let's consider that the pipeline is filled by the air and the velocity propagation of acoustic signals is 340m/s. The gas flow velocity inside the pipeline exceeds 10m/s. How it is seen from Fig.2 under the above mentioned boundary conditions, the deflection Δl_1, stipulated by the first term, may increase to 4,5m/s when determining the leakage co-ordinates. When acoustical noises from the damaged place to the nearest electroacoustical transducer are propagating downstream the gas flow, the determined leakage place it will be nearer the end of the pipeline under investigation than the real one (curves 1 – 3 in Fig. 2). When the acoustical noises are propagating to the nearest transducer upstream the gas motion in the pipeline the calculated leakage place moves nearer the centre of the controllable section in comparison to the real place (curve 4 – 6 in Fig.2). The deflection Δl_2, which is stipulated by the second term in the (7) equation, under the given conditions, achieves only 0,13m (Fig.3). In accordance with the measuring error $\Delta l \approx 0{,}5$m which is permissible when determining the co-ordinates of the leakage, the influence of deflection which is cost by the second term in the right side of (7) equation may be denied. Therefore the (7) equation may be described

$$\Delta l \approx \Delta l_1 = \frac{lv}{2(c+v)}. \tag{8}$$

How it is seen from (7) when the leakage co-ordinates of the pipeline are determined by the (1) algorithm, the absolute deflection of the determined leakage place is increased when the gas motion velocity and the length of the pipe section under investigation are increased. But it is decreased when the sound speed in the gas fulfilling the pipeline is rising.

Now let us to estimate the influence of temperature variation inside the gas pipeline when determining the leakage co-ordinates by acoustic correlation method. While carrying out the hydraulic tests, the pressure inside the pipeline is raised rapidly to the several atmospheres. Depending on the length and diameter of the pipeline under investigation and on the capacity of the compressor it lasts from 2...3 to 10...12 minutes.

Since the gas pipeline from outside is covered by the anticorrosive insulation that is bad heat conductor too, one can say that there is the closed thermodynamic system consisting from the pipe walls and the gas fulfilling the pipeline. In such a system, referring on a law of energy, conservation, the work A is accomplished while compressing the gas and part of energy is transferred to the walls of pipeline as a heat Q. Another part of energy is converted to the internal energy U of the gas filling the pipeline. In the difference form it may be written

$$dA = dQ + dU. \tag{9}$$

When considering that the thermal capacity C of the system under investigation is constant and on the ground of lows of physics [13] from the (9) equation it may be written

$$Vdp + pdV\left(\frac{\mu(m_s c_s - m_d c_v) + m_d R}{\mu(m_s c_s - m_d c_v)}\right) = 0. \tag{10}$$

Here p is the gas pressure, dV is an increment of gas volume; m_s and m_d are the mass of the pipe and the gas, respectively; c_s is the specific heat of the pipe wall material; c_v is specific heat of the gas filling the pipeline; μ is the molar mass of the gas filling the pipeline; R is universal gas constant. After the designation

$$n = \frac{\mu(m_s c_s - m_d c_v) + m_d R}{\mu(m_s c_s - m_d c_v)}, \tag{11}$$

applying the Clapeyron equation and considering that n=const from the (10) equation one can receive

$$T = T_0\left(\frac{p}{p_0}\right)^{\frac{n-1}{n}}. \tag{11}$$

Here T_0 and p_0 are an initial gas temperature and initial gas pressure, respectively.

After the substitution (11) expression into the (12) equation and after the expression of the gas mass by its density and pressure it may be obtained

$$T = T_0\left(\frac{p}{p_0}\right)^{\frac{\rho_{atm} r R p}{\mu(2\rho_s c_s h p_{atm} - \rho_{atm} c_v r p)}}. \tag{13}$$

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Here r is the inside radius of the pipeline; h is the thickness of the pipe wall; ρ_s is the density of the pipe wall material; ρ_{atm} and p_{atm} are the density and pressure of the gas under the normal conditions, respectively; p is the gas pressure inside the pipe.

The algorithm (13) allows one to estimate the alteration of the gas temperature when the compressor rapidly raises the pressure in the gas pipeline. The variation of the gas temperature inside the steel pipeline of different diameter (pipeline wall thickness h=3mm) when the pressure is raised is shown in Fig.4.

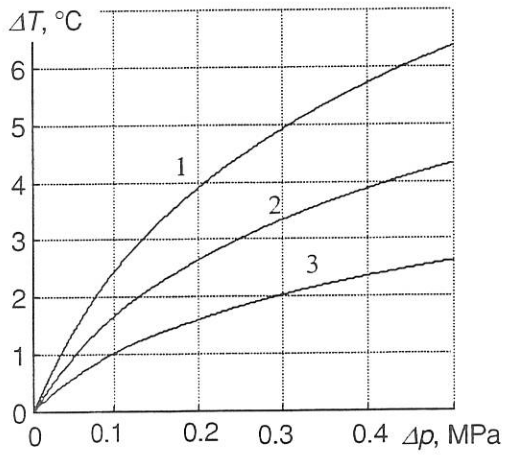

Fig. 4. The gas temperature dependence on the pressure inside the pipeline when the radius of the pipe: *1*-100mm, *2*-75mm, and *3*-50mm.

Since the velocity propagation of acoustical signals in the gas is described by an equation

$$c = \sqrt{\gamma \frac{RT}{\mu}}, \tag{14}$$

thought the difference of the acoustic signal propagation velocity $\Delta c = c - c_0$ when the gas pressure alteration velocity is big may be expressed by the equation

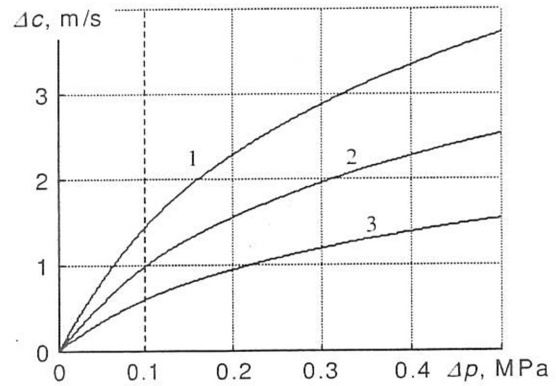

Fig. 5. The dependence of propagation velocity of acoustical signals upon the variation of pressure in the gas pipeline when the radius of pipeline: *1* – 100mm; *2* – 75mm; *3* – 50mm.

$$\Delta c = \sqrt{\frac{\gamma R T_0}{\mu}\left[\left(\frac{p}{p_0}\right)^{\frac{\rho_{atm} r R p}{\mu(2\rho_s c_s h p_{atm} - \rho_{atm} c_v r p)}} - 1\right]}. \tag{15}$$

Here γ is the adiabatic exponent of the gas (γ=1,41 for an air).

The variation of the speed propagation of acoustic signals in the pipeline when gas pressure is raised, while hydraulic tests are fulfilled, is shown in Fig.5.

During the hydraulic tests, when the leakage co-ordinates are determined by the acoustic correlation method, the algorithm (1) it is used. The velocity propagation of the acoustic signal is taken equal to the sound velocity in the gas media under the ambient temperature T_0. However, like it was shown earlier, the gas temperature and the sound speed in the pipeline are rising when the compressor increases the pressure in the gas pipeline. At such a way, the real place of leakage l_1^* in the gas pipeline may be obtained

$$l_1^* = \frac{l - c^* \Delta t}{2}. \tag{16}$$

Here c^* is the velocity propagation of the acoustic signals in the pipeline under the temperature T_1.

By using (1) and (16) equations one can determine the absolute deflection of the leakage place $\Delta l = l_1 - l_1^*$ when it is used (1) algorithm and when the change of gas temperature in the gas pipeline is not taken into account

$$\Delta l = l_1^* \frac{\Delta c}{c^*} - l \frac{\Delta c}{2c^*}. \tag{17}$$

Here $\Delta c = c - c_1^*$. How it is seen from the (17) equation

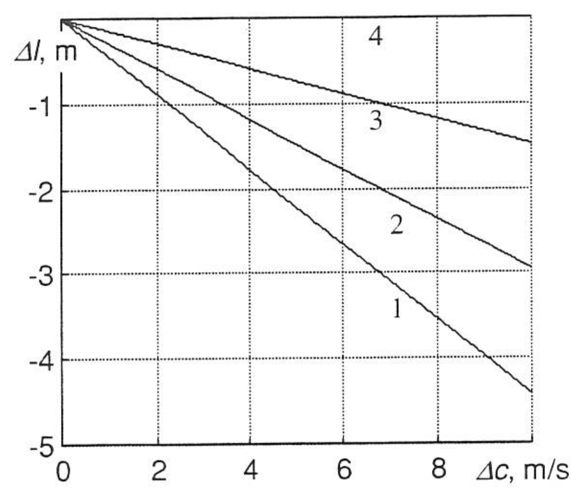

Fig. 6. The dependence of the absolute deflection of the leakage place on the sound velocity increment when the pipeline length l=300m and distances from the transducer to the leakage place: *1*-0m, *2*-50m, *3*-100m and *4*-150m.

an absolute deflection of the determined leakage place depends the co-ordinates Δl^{*} of the leakage in the gas pipeline (Fig.6) and on the length l of the pipeline under investigation (Fig.7).

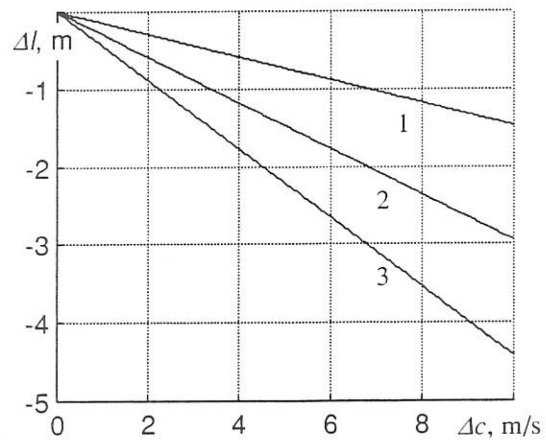

Fig. 7. The dependence of the absolute deflection of the leakage place on the sound velocity increment when the leakage is near the electroacoustical transducer and the pipe lengths: *1*-300m, *2*-200m and *3*-100m.

CONCLUSIONS

The modelling results shows that when the leakproofness of the gas pipeline transporting gaseous products is investigated under the normal exploitation conditions or when the hydraulic tests are fulfilled the algorithm (1) can't be used directly without consideration the measuring conditions.

Under the above mentioned measuring conditions an absolute deflection of the leakage place caused by the gas motion inside the gas pipeline in separate cases may exceed more than 4 meters. The basic influence to the absolute deflection Δl of the determined leakage co-ordinates is caused by the length of the pipe section under investigation and by the flow velocity inside the pipeline. It is entirely independent from the co-ordinates of the leakage place in the pipeline. The most absolute deflection of the leakage co-ordinates caused by the change of the leakage place exceeds only 0,13m. Therefore when the (1) algorithm it is used for determination of the leakage co-ordinates, the deflection caused by the motion of transporting gaseous products which may be evaluated by the (8) algorithm must be taken into account.

On the other hand, when the damaged place of the gas pipeline is determined by the hydraulic tests, the absolute deflection of the determined co-ordinates of the leakage may achieve several meters if the gas temperature change is not evaluated. The deflection is in straight proportion with the pipeline length and with the distance of leakage from the centre of the pipeline under investigation. Therefore, with the purpose to minimise the earthwork volume while removing the leakage's which were detected by the hydraulic tests, it is necessary to determine more precisely the temperature of the gas filling the pipeline. Especially it is actual when acoustic correlation method is applied for determination the leakage co-ordinates in the gas pipelines of high pressure, when the pressure while performing the hydraulic tests is raised to the several tens of atmospheres.

REFERENCES

1. .Дробот Ю. Б., Грешников В. А., Бачелов В Н. Акустическое контактное течеискание. Москва: Машиностроение, 1989. - 120 с. (In Russian).
2. Jakevičius L., Tumšys O., Gudavičius G. The analysis of influence of acoustic signal reflection in pipelines to correlation function of these signals // Electronics and engineering. – Kaunas: Technologija, 1997. – No.2(11). – P. 49 - 51. (In Lithuanian).
3. Jakevičius L., Tumšys O., Butkus J. An influence of reflection for acoustical correlotion measurements in the pipelines // Otwarte Seminarium z Akustiki. Poznan-Kiekrz, 15 - 18 wrzešnia 1998. P. 247 - 252
4. Jakevičius L., Butkus J., Jucius D., Gudavičius G. An acoustical method for detection of leakage of gas-pipe line // Electronics and electrical engineering. - Kaunas: Technologija, 1995. – No.1. – P. 69 – 72. (In Russian).
5. Тумшис О., Якявичюс Л. Акустическая система для обнаружения утечек в газопроводах низкого давления // Измерительная техника. 1998. №. 5. С. 56 - 58. (In Russian).
6. Gudavičius G., Jakevičius L., Tumšys L., Butkus J. The methods for decerasing of influence of acoustical signal's reflections when searching the leakage of pipelines // Ultragarsas. - Kaunas: Technologija, 1996. – No.1(26). – P. 26 – 28. (In Lithuanian).
7. Butkus J., Jakevičius L., Tumšys O. An acoustical method for determination of leakage coordinates in the pipelines // Archives of acoustics. - Warszawa. 1998. Vol. 23. No.4. P. 533 - 539
8. Годлевский В. С., Владимирский А. А., Владимирский И .А. Методика применения корреляционного течеискателя "Коршун". - Киев, 1992. - 46 с. (In Russian).
9. Загоскин В. Н, Венгерцев Ю. А., Казак А. С., Яковлев Е. И. Применение ЭВМ для обнаружения утечек на нефтепродуктопроводах / Серия: Транспорт и хранение нефтепродуктов и углеводородного сырья., Но1. -М., 1989 - 60 с. (In Russian).
10. Jakevičius L., Tumšys O., Butkus J., Gudavičius G. Acoustical methods for control of the pipelines of energy objects, problems, solutions and perspectives / Contributed papers of the Republic conference „Heat energy and technologies„ - Kaunas: Technologija, 1996. – P. 44 – 50. (In Lithuanian).
11. Jakevičius L., Butkus J., Tumšys O. Investigation singularities of propagation of acoustical noises generated in places of unhermeticy of pipelines // Electronics and electrical engineering. - Kaunas: Technologija, 1998. – No.5(18). – P. 16 – 18. (In Lithuanian).

12. Jucius D., Butkus J., Jakevičius L., Tumšys O. An acustical method for detection of leakage of gas pipelines / Proceedings of 23-rd European Conference on Acoustic Emission Testing. Viena. Austria: 6-8 may 1998. P. 164 - 169.
13. Яколев В. Ф. Курс Физики. Москва, 1976. – 320.с. (In Russian).

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