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EXPERIMENTAL VERIFICATION OF THE THEORETICAL MODEL OF THE THERMAL DETECTOR OF FLOW REVERSAL

WERYFIKACJA DOŚWIADCZALNA TEORII CIEPLNEGO INDYKATORA ODWRÓCENIA PRZEPŁYWU

The paper presents the reasoning leading to experimental verification of the theory describing the operation of a sensor used for flow reversal detection. The sensor is consists of two hot, parallel wires at a lose distance so they can interact with one another. They lie one behind the other, on the plane parallel to flow velocity. The wires are normal to the velocity vector. The distinctive feature of this sensor is that the two wires, connected in series, are supplied from one CTA system, which means that the sum of wires' resistance is maintained on a preset, constant level. Voltage difference across the wires is the measured parameter.

Theoretical considerations presented in the work of [Gawor et al., 1999] and [Kiełbasa, 2000a] yield the formula (1) providing the relationship between the difference in wire temperatures and sensor geometry and physical parameters of the flowing medium. The problem is that the researcher does not directly measure the temperature of hot wires but the voltages across the wires when surrounded by the flowing medium. The relationships are based on thus measured voltages and the conditions of constant-temperature principle of operation.

Key words: direction of velocity vector, flow reversal, flow reversal detector.

W artykule przedstawiono tok rozumowania prowadzący do eksperymentalnej weryfikacji teorii opisującej pracę czujnika przeznaczonego do wykrywania odwrócenia prędkości przepływu. Czujnik składa się z dwu grzanych równoległych włókien, niezbyt odległych, tak że oddziaływują cieplnie na siebie, leżących jeden za drugim w płaszczyźnie równoległej do prędkości przepływu (patrz rys. 1). Włókna są prostopadłe do wektora prędkości. Cechą charakterystyczną tego czujnika jest to, że oba włókna, połączone szeregowo zasilane są

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z jednego układu stałotemperaturowego (CTA), co oznacza, że suma rezystancji obu włókien jest utrzymywana na stałym zadanym poziomie. Mierzy się różnicę napięć występujących na włóknach.

Teoretyczne rozważania podane w pracy [Gawor i in., 1999] oraz w pracy [Kiełbasa, 2000a] prowadzą do zależności (1) wiążącej różnicę temperatur między grzanymi włóknami a parametrami geometrycznymi czujnika i fizycznymi przepływającego medium. Problem w tym, że eksperymentator nie mierzy temperatury nagrzanych włókien, lecz napięcia występujące na grzanych włóknach w zaistniałych warunkach ich opływu. Z napięć tych i warunku, że włókna pracują w układzie anemometru stałotemperaturowego wyprowadzono zależność wiążącą poszukiwaną funkcję $F(r_0, l, h)$ z mierzonymi napięciami U_c i U_s. Postać tej zależności podana jest wzorem (9) lub (10).

Kilka takich dwuwłóknowych czujników przebadano w tunelu aerodynamicznym, w którym realizowano przepływy powietrza od zera do 1 m/s. W ściance tunelu zamontowano obrotowy uchwyt sterowany silnikiem krokowym, przez który wprowadzano badany czujnik do tunelu. Uchwyt miał możliwość obrotu w pełnym kącie z niepewnością ustawienia ok. 0,2°. Kąt obrotu sondy ustawiano komputerowo. W eksperymencie sondę ustawiano tak, że grzane włókna były w położeniu pionowym. Przez obrót sondy o 180° zamieniano rolę włókien, co było równoważne odwróceniu przepływu powietrza w kanale.

Słowa kluczowe: zwrot prędkości, odwrócenie prędkości, detektor zwrotu przepływu.

NOMENCLATURE

c — specific heat of the flowing medium at constant pressure,
l — distance between the hot wires,
n — overheat ratio for two wires (connected in series),
v — velocity of flowing gas,
I — current supplying the sensor,
R_{w1} — cold resistance of the first wire,
R_{w2} — cold resistance of the second wire,
R_{w0} — total resistance of the two wires (cold),
T_g — temperature of the flowing medium,
T_{w0} — temperature of the wire for preset overheating ratio,
T_{w1} — temperature of the first wire,
T_{w2} — temperature of the second wire,
U_s — voltage across the first wire (in the middle section of the sensor),
U_c — voltage across the two wires (total),
γ — temperature coefficient of wire resistance,
κ — thermal difussion coefficient of the flowing medium,
λ — thermal conductivity of the flowing medium,
ϱ — density of the flowing medium,
ΔT — difference in wires' temperatures,
ΔU — voltage difference between the two wires.

1. Introduction

The thermal probe shown in Fig. 1 was tested experimentally with the use of test facilities including the wind tunnel (calibrated beforehand using the thermal wave method [Kiełbasa, 1996]), a data acquisition device a computer — controlled device which turns the tested sensor around the support axis. A two-wire anemometric sensor is incorporated into a bridgeless CTA circuit developed by Ligęza, and discussed in the short paper of [Gawor et al., 1999]. This anemometer was designed to meet the necessary requirements of those tests and enables computer control of the overheating ratio.

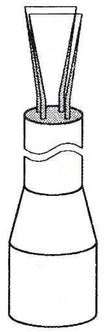

Fig. 1. Thermal (interaction) sensor

A part of the anemometer circuit showing the exacts points where voltage measurements were taken is presented in Fig. 2. Only the elements required for furhter analyses are indicated.

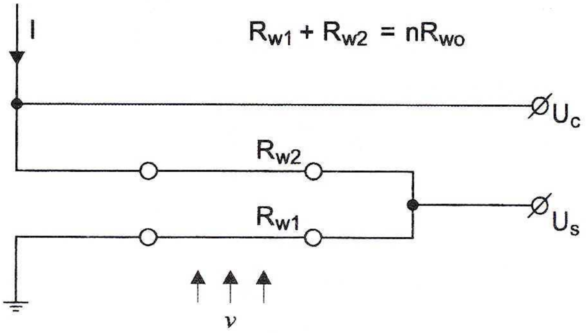

Fig. 2. Voltage measurement points in two-wire sensors

2. Experimental verification of the theoretical model

"Cold" resistance of the sensor (the sum of resistances $R_{w1}+R_{w2} = R_{wO}$) was measured in precisely controlled conditions. Then the overheating ratio was selected and the anemometer was switched to operation mode. Voltages U_c across the two resistors, and voltage U_s across the resistor R_{w1} were the measured parameters. Before the sensor is connected to the anemometer circuit it is necessary to carefully measure the distance l between the wires. Measurements were taken for the two pairs of support prongs and the mean value was calculated. Wire length d was measured, too.

This experiment was run to verify the formula presented in quoted papers where temperature difference between the two wires is given as:

$$\Delta T = \frac{2(n-1)K_0(|h|r_0)\sin h(hr_0) + K_0(|h|l)\sin h(hl)}{\gamma\, K_0(|h|r_0)\cos h(hr_0) + K_0(|h|l)\cos h(hl)} = \frac{2(n-1)}{\gamma} F(r_0, l, h), \tag{1}$$

where:

$$h = \frac{v}{2\kappa}. \tag{2}$$

ΔT stands for difference in temperatures of wires operating within CTA circuit, n — preset overheating ratio of two wires connected in series, γ — temperature coefficient of wire resistance, r_0 — wire radius, l – distance between the wires, K_0 (...) — Bessel function of the zero order.

The reasoning here is as follows: Assuming the linear relation between wire resistance and temperature, we can write:

$$R_{w1} = R_{w01}\left(1 + \gamma(T_{w1} - T_g)\right) \tag{3}$$

and assuming that the temperature of the flowing gas T_g changes very slightly,

$$R_{w2} = R_{w02}\left(1 + \gamma(T_{w2} - T_g)\right) \tag{4}$$

after simple transformations we get:

$$\Delta T = \frac{R_{w1} - R_{w2}}{\gamma R_{w0}}. \tag{5}$$

Basing on Fig 2, we get:

$$R_{w1} = \frac{U_s}{I} \tag{6}$$

and

$$R_{w2} = \frac{U_c - U_s}{I}, \tag{7}$$

$$I = \frac{U_c}{n R_{w0}}. \tag{8}$$

Substituting these three relationships into (5) and bearing in mind that U_s is the voltage across one of the wires and $U_c - U_s$ — voltage across the other wire, we get:

$$\Delta U = U_s - (U_c - U_s) = 2U_s - U_c$$

which is the voltage difference between the two wires. Hence we get:

$$\Delta T = \frac{n}{\gamma}\left(\frac{2U_s - U_c}{U_c}\right) = \frac{n\Delta U}{\gamma U_c}. \tag{9}$$

When (9) is substituted in (5), we get:

$$F(r_0, l, h) = \frac{n}{2(n-1)}\frac{\Delta U}{U_c}. \tag{10}$$

Thus obtained formula is the basis for experimental verification of the theoretical model of a thermal anemometer operating in CTA system.

3. Inaccuracy involved in determination of the function $F(r_0, l, h)$

The relative inaccuracy of the function F can be determined using the logarithmic derivative method. Finding the logarithm and differentiating (10), we get:

$$\frac{\Delta F}{F} = \left|\frac{\Delta n}{n}\right| + \left|\frac{\Delta n}{n-1}\right| + \left|\frac{\Delta(\Delta U)}{\Delta U}\right| + \left|\frac{\Delta U_c}{U_c}\right|.$$

Assuming $\Delta n = 0.002$ (it is an estimate based on accuracy of CTA resistors); $\Delta U = 10$ mV; $\Delta(\Delta U) = 0.2$ mV; $\Delta U_c = 0.1$ mV, overheating ratio $n = 2$ and $U_c = 2$ V, we get:

$$\frac{\Delta F}{F} = \left|\frac{0.002}{2}\right| + \left|\frac{0.002}{1}\right| + \left|\frac{0.002}{10}\right| + \left|\frac{0.001}{2}\right| \simeq 2.305\%.$$

Thus the inaccuracy involved in wire voltage measurements is the major component of inaccuracy involved in experimental determination of the function F. It is clear that those calculations are valid only for ΔU_s other than zero. When $\Delta U_s = 0$ it is necessary to find the absolute inaccuracy, which is not difficult.

4. The measuring stand

The two wire sensor was tested in the laboratory of Strata Mechanics Research Institute in Kraków, in a small wind tunnel enabling air flows from 0–1 m/s. A rotating holder, controlled with a step motor, was fitted in the tunnel wall. It was used to insert the tested sensor into the tunnel. The holder could be rotated by the full angle, with the precision of 0.2°. The rotation angle was computer-controlled. When the sensor was revolved by 180°, the roles of the two wires were reversed, which as equivalent to air flow reversal.

The hot wire sensor is supplied from the bridgeless CTA where the overheating ratio is set digitally from a computer (Fig. 3). At the anemometer output are the voltages: U_c — supplying the two wires connected in series and U_s — voltage at the point where the wires are connected (in the middle section).

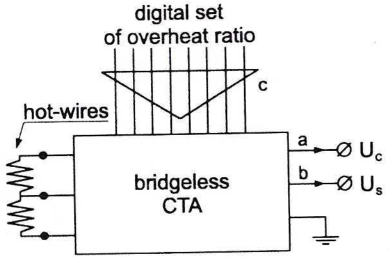

Fig. 3. Anemometer used as flow reversal detector — block diagram

Voltage signals U_c and U_s were acquired every 10 ms for 1 s, they were then averaged and stored on a disc together with all the preset measurement parameters. The measuring stand shown in Fig. 4 in the form of a block diagram was controlled via an IBM 586 computer with the card with a 16 inputs 14-Byte a/d converter and a 2 inputs 12-Byte d/a converter.

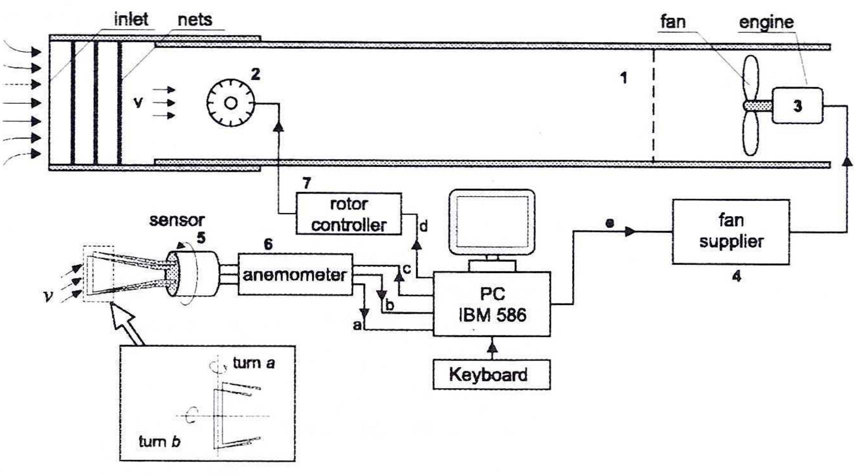

Fig. 4. The measuring stand (block diagram): 1 — wind tunnel, 2 — rotating holder, 3 — fan motor, 4 — fan supplier, 5 — tested sensor, 6 — anemometer supplying the sensor, 7 — rotor supply, a...e — lines connecting the elements with the computer

The computer was used to:

1. Generate the voltage signal 0–10 V which controls the power supply to fan motor.
2. Generate the digital signal which is passed to the motor rotating the holder.
3. Generate the digital signal which controls the wire overheating ratio (Fig. 3).
4. Measure the voltages U_c and U_s across the tested sensors.

5. Gather N preset measurements, average the results and store them on the disc together with all parameters peset for the experiments.

6. Change the parameters in accordance with the approved algorithm and repeat the series of measurements.

Tested probes were made of tungsten wire 5, 8 or 10 micrometer in diameter. The probe length was 10 mm and the distance between the wires ranged from 0.2 to 2 mm. The sensor was fixed in the holder in such a way that the wires were arranged vertically and their plane was parallel to the tunnel axis. The middle points of the wires were on the tunnel axis. For each wire arrangement, fan rotations were first determined for the preset velocity (which ranged from 0 to 1 m/s with the step 5 cm/s), then the overheating ratio was determined. Voltages U_c and U_s were read off for each value of the overheating ratio, they were then averaged and stored. The overheating ratio was then changed and the measurement was repeated. When the preset overheating values were all considered, the flow velocity was changed by the preset step and U_c and U_s were measured in accordance with the algorithm. The measurements for all preset flow velocities being accomplished, the sensor was rotated by 180° and the measurement cycle was repeated accordingly.

When this part of experiment was accomplished, the values obtained in the course of subsequent measurements were averaged. Thus obtained results are summarised in two tables. The voltages $U_c(i, k)$, that is total voltages (across the two wires) for the i-th overheating and k-th flow velocity are presented in the first table. In the second table we can find the voltage $U_s(i, k)$ across one of the sensor halves taken in the same conditions. The third and fourth table provide the standard deviations relevant to the elements in the first and second table.

The preamble summarised all parameters of the experiment: date, temperature, wire diameter, wire lenght, total "cold" resistance of the two wires.

5. Results

Selected results obtained for a two-wire sensor acting as the flow reversal detector are presented in Fig. 6 – 11 (for three wire diameters; 5, 8, 10 micrometers and for variable distance between the wires). The hot wires were made of tungsten, 10 mm in length. Fig. 12 presents experimental results of the function $F(r_0, l, v)$ obtained for the wire 10 mm in diameter and for various distaces between the wires.

Those diagrams lead us to the following conclusions:

1. Experimental characteristics of the two wire sensor defined with the function $F(r_0, l, h)$ are antisymmetric with respect to the flow velocity direction. In qualitative terms they resemble the theoretical characteristics presented in Fig. 5, derived from (1).

2. The function $F(r_0, l, h)$ derived from the measurement data has a continuous transition through the zero velocity with the derivative other than zero (the greatest one throughout the whole characteristics).

3. The inclination of the derivative depends on the distance between the wires (ζ).

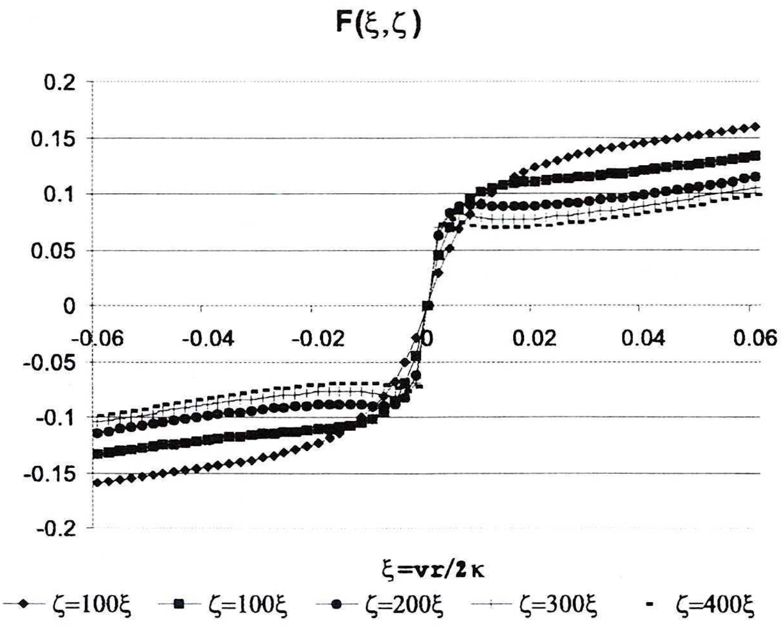

Fig. 5. Theoretical plots of the function $F(\xi, \zeta)$ for various ζ

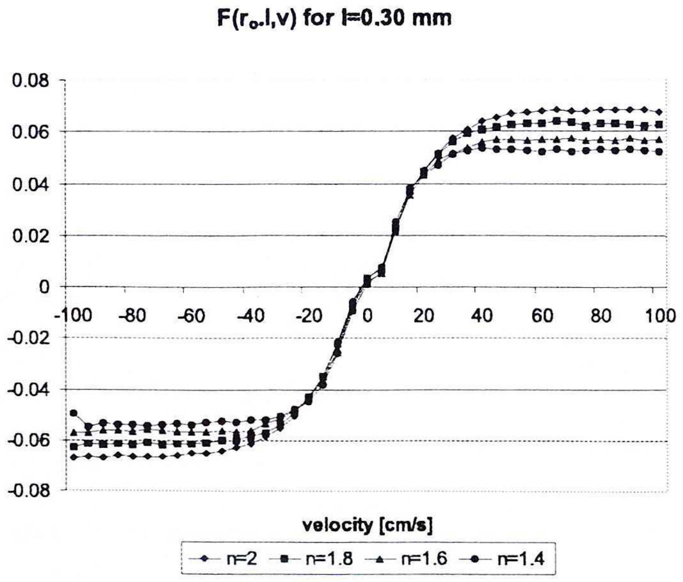

Fig. 6. The function $F(r_0, l, v)$ for various values of wire overheating n and the distance between the wire $l = 0.3$ mm. Wire diameter: 5 μm; wire length: 10 mm

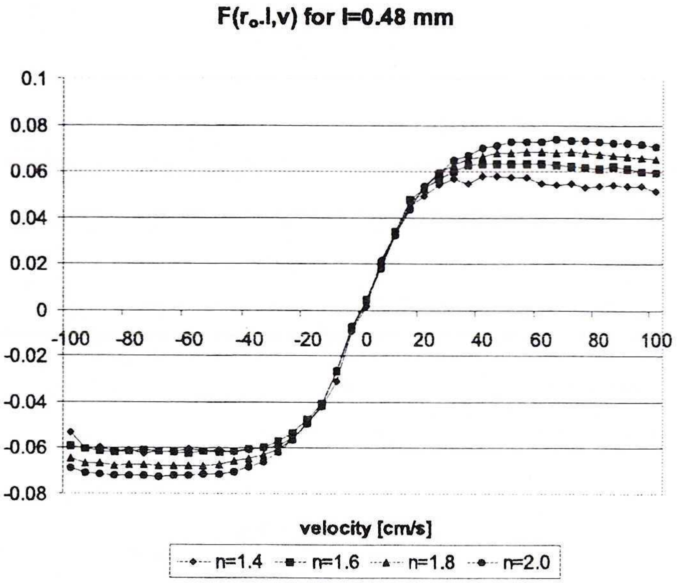

Fig. 7. The function $F(r_0, l, v)$ for various values of wire overheating n and the distance between the wire $l = 0.48$ mm. Wire diameter: 5 μm; wire length: 6 mm

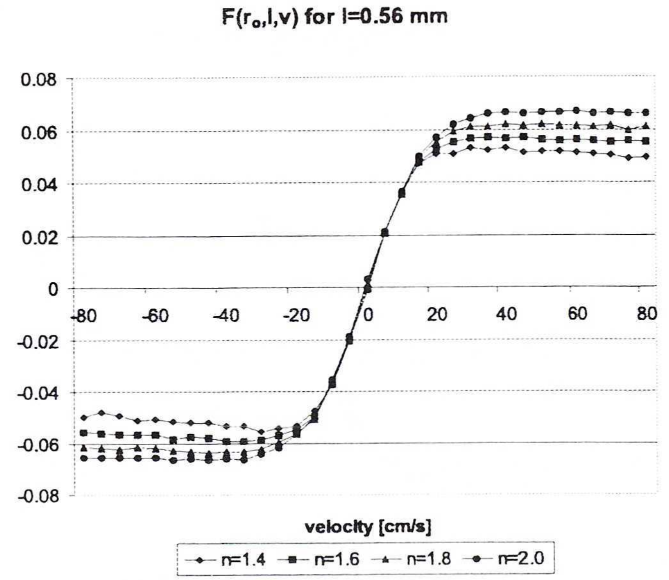

Fig. 8. The function $F(r_0, l, v)$ for various values of wire overheating n and the distance between the wire $l = 0.5$ mm. Wire diameter: 8 μm; wire length: 10 mm

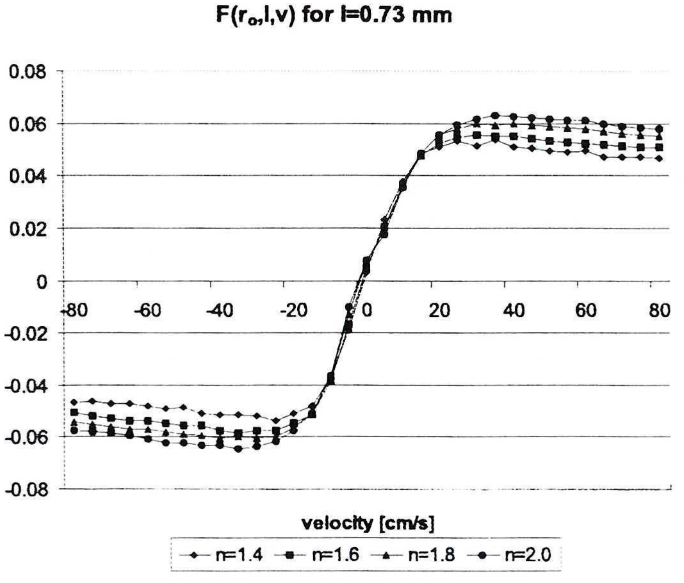

Fig. 9. The function $F(r_0, l, v)$ for various values of wire overheating n and the distance between the wire $l = 0.73$ mm. Wire diameter: 8 μm; wire length: 10 mm

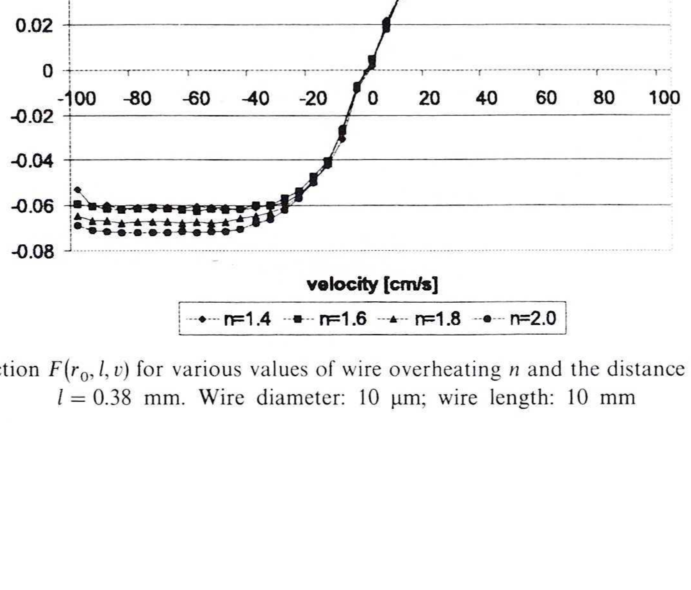

Fig. 10. The function $F(r_0, l, v)$ for various values of wire overheating n and the distance between the wire $l = 0.38$ mm. Wire diameter: 10 μm; wire length: 10 mm

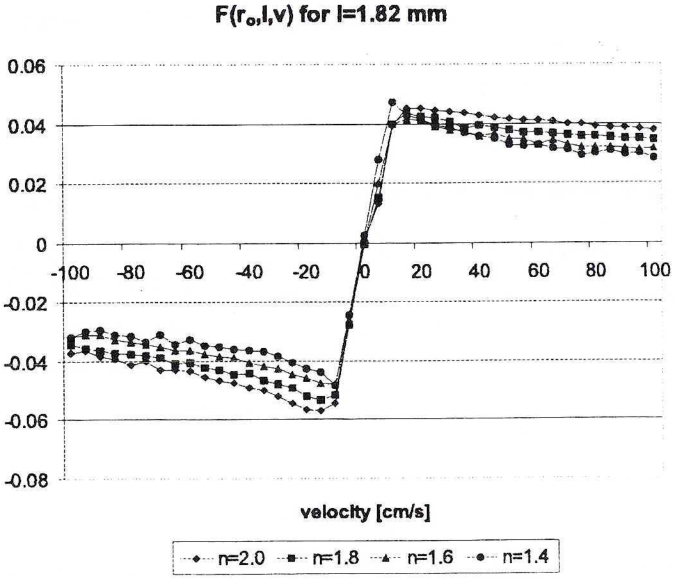

Fig. 11. The function $F(r_0, l, v)$ for various values of wire overheating n and the distance between the wire $l = 1.82$ mm. Wire diameter: 10 μm; wire length: 10 mm

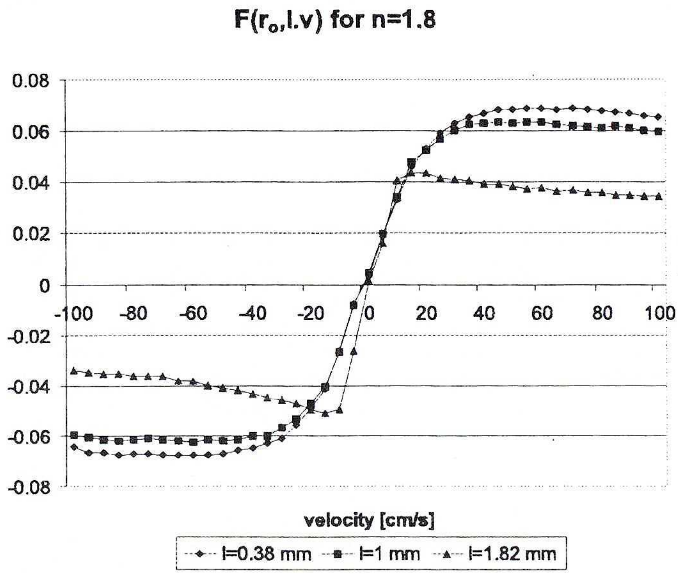

Fig. 12. The function $F(r_0, l, v)$ for various distance between the wire. Wire diameter: 10 μm

4. In some cases we observe two extreme points, which in related to ratio of the wire diameter to the distance between the wires.

5. The values of the function $F(r_0, l, v)$ obtained experimentally are similar to those obtained from theoretical considerations although the exact value of κ for air was not available then. That is due to the fact that air temperature around the wires is unknown and can be estimated only.

6. The voltage U_c across the wires is the monotonic function of velocity modulus. It is available to the researcher all the time.

7. Electronic combination of the total voltage U_c and the voltage difference ΔU yields information about the magnitude and direction of velocity vectors. The voltage ΔU is transformed into a unit signal within the Schmitt circuit, in accordance with the formula $F(\Delta U) = 1$ when $\Delta U > \Delta U_{min}$ and $F(\Delta U) = 0$ when $\Delta U \leqslant \Delta U_{min}$. Since the tested sensor affords a continuous transition through the zero velocity with the derivative $\frac{d\Delta U}{dv} \neq 0$, then the dead band of the Schmitt circuit can be vastly reduced. Output voltage from the Schmitt circuit controls the sign of the amplifier gain. Total voltage U_c from the two wire sensor is supplied to the amplifier's input (-).

8. Measurement points are slightly scattered as the tunnel used in the experiments is an open one and the flows could be disturbed by pressure gradients in the laboratory room due to wind outside the building.

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BOUNDARY CONDITIONS FOR ELEMENTARY FUNCTIONS OF PROBABILITY DENSITIES FOR THE PRODUCTION PROCESS REALISED IN LONGWALLS

WARUNKI BRZEGOWE DLA ELEMENTARNYCH FUNKCJI GĘSTOŚCI PRAWDOPODOBIEŃSTWA PROCESU PRODUKCYJNEGO REALIZOWANEGO W PRZODKU ŚCIANOWYM

Fundamental criterion for assessment of the efficiency of production process realised in a longwall is the lack of breaks in work of mining machine (except breaks which result from the technology applied or operation schedule).

Rated outputs for machines which are used in longwalls are high enough so that only other reasons can cause that it is impossible to make full use of these machines. Among these reasons can be listed e.g. geology-mining conditions which occur in the studied longwall (Sikora, 1991).

The author undertook the study in which numerical model of production process which is carried out in the longwall was used. The model was described in (Snopkowski, 2000).

In this model, it is assumed that time periods for realisation of activities and operations realised in the longwall, which influence the advance of the heading machine, are given in the form of elementary functions of probability densities. The term "elementary" was proposed by the author in order to differentiate these functions from other functions and because these functions describe realisation time in units [minute/meter]. The model is a simulation model (software written in FORTRAN) and it enables to fully reflect of the actual run of the production process with keeping the rules which result from the technology which is used.

In three samples of calculations, different relations between elementary functions of probability densities were assumed. Those assumptions resulted from different geology-mining conditions which occurred in longwalls. The influence of those relations on time of the production cycle was determined. The total time of heading machine breaks during "mining" along the whole longwall length was registered.

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On the base of calculations which were performed, the following boundary conditions for elementary functions of probability densities were suggested:

$$\begin{cases} \int_a^{+\infty} f_e(t_u)dt_u - \int_a^{+\infty} f_{e_1}(t_1)dt_1 > 0 \\ \int_a^{+\infty} f_e(t_u)dt_u - \int_a^{+\infty} f_{e_2}(t_2)dt_2 > 0 \\ \vdots \quad \vdots \quad \vdots \quad \vdots \\ \int_a^{+\infty} f_e(t_u)dt_u - \int_a^{+\infty} f_{e_i}(t_i)dt_i > 0 \end{cases}$$

for each value "a" > 0,
where:

$f_e(t_u)$ — elementary function of probability density for variable T_u – mining time by heading machine on 1 meter distance,

$f_{e_1}(t_1), f_{e_2}(t_2) \ldots f_{e_i}(t_i)$, — elementary functions of probability densities for activities or operations carried out simultaneoulsy (paralelly) with mining by heading machine when realisation of these influence the movement of the heading machine.

Key words: coal mining, efficiency of production operation, probability distribution.

Istotnym kryterium efektywności procesu produkcyjnego realizowanego w przodku ścianowym jest brak przerw w pracy maszyny urabiającej (poza przerwami wynikającymi z technologii lub organizacji procesu).

Wydajności nominalne maszyn wykorzystywanych w przodkach ścianowych są na tyle duże, iż jedynie inne przyczyny mogą powodować, że niemożliwe jest ich pełne wykorzystanie. Tymi przyczynami mogą być np. warunki geologiczno-górnicze danego przodka ścianowego (Sikora, 1991).

Autor przeprowadzał w tym zakresie badania, w których wykorzystano numeryczny model procesu produkcyjnego realizowanego w przodku ścianowym, opisany w pracy (Snopkowski, 2000).

W modelu tym zakłada się, że czasy realizacji czynności i operacji realizowanych w ścianie, a mających wpływ na posuw kombajnu, są przedstawiane w postaci elementarnych funkcji gęstości prawdopodobieństwa. Określenie „elementarnych" autor wprowadził w celu odróżnienia od innych funkcji oraz biorąc pod uwagę to, że opisują czas realizacji w jednostkach [minut/metr]. Przedmiotowy model jest modelem symulacyjnym (program w języku FORTRAN) i umożliwia wierne odzwierciedlenie przebiegu rzeczywistego procesu produkcyjnego z zachowaniem reguł wynikających ze stosowanej technologii.

W trzech przykładach obliczeniowych założono różne relacje między wybranymi elementarnymi funkcjami gęstości prawdopodobieństwa, przyjmując, że przyczyną tych relacji mogą być warunki geologiczno-górnicze danego przodka ścianowego. Badano wpływ tych relacji na czas trwania cyklu produkcyjnego. Rejestrowano także sumaryczny czas postoju kombajnu w trakcie „urabiania" na całej długości ściany.

Na podstawie przeprowadzonych obliczeń sformułowano dla elementarnych funkcji gęstości prawdopodobieństwa następujące warunki brzegowe:

$$\begin{cases} \int\limits_a^{+\infty} f_e(t_u)dt_u - \int\limits_a^{+\infty} f_{e_1}(t_1)dt_1 > 0 \\ \int\limits_a^{+\infty} f_e(t_u)dt_u - \int\limits_a^{+\infty} f_{e_2}(t_2)dt_2 > 0 \\ \vdots \quad \vdots \quad \vdots \quad \vdots \\ \int\limits_a^{+\infty} f_e(t_u)dt_u - \int\limits_a^{+\infty} f_{e_i}(t_i)dt_i > 0 \end{cases}$$

dla każdej wartości „a" większej od zera,
gdzie:

$f_e(t_u)$ — elementarna funkcja gęstości prawdopodobieństwa zmiennej T_u — czas urabiania kombajnem na odcinku 1 metra,

$f_{e_1}(t_1), f_{e_2}(t_2) \ldots f_{e_i}(t_i)$, — elementarne funkcje gęstości prawdopodobieństwa dla czynności lub operacji wykonywanych równocześnie (równolegle) z urabiającym kombajnem, których realizacja wpływa na posuw kombajnu.

Słowa kluczowe: górnictwo węgla kamiennego, efektywność procesu produkcyjnego, rozkład prawdopodobieństwa.

Fundamental criterion for assessment of the efficiency of production process realised in a longwall is the lack of breaks in work of mining machine (except breaks which result from the technology applied or operation schedule). Data presented in (Fawcett, Duncan, 1990) showed that for 58% of longwalls mining was slowed down by the velocity of dislocation of mechanical support systems.

Rated outputs for machines which are used in longwalls are high enough so that only other reasons can cause that it is impossible to make full use of these machines. Among these reasons can be listed e.g. geology-mining conditions which occur in the evaluated longwall (Sikora, 1991).

In mining practice, it is very difficult to determine whether heading machine can be stopped or not without using large resources (people, sensors, etc.) for thorough monitoring of the process. If someone wanted to carry out such study in the case of a real longwall, it would be necessary to do it during sufficiently long time period in order to achieve reliable enough statistical results.

According to author's opinion, assuming costs and opportunity that obtained results can be assigned only to the longwall studied, monitoring of the process under real conditions is not justifiable.

Author suggests that the model developed within the scope of "Methods of probability distribution identification for output obtained in longwall of coal mines" should be used. Assumptions, structure and algorithms used in this model were presented in (Snopkowski, 2000). Because of extensiveness of this description, it is not possible to cover it in this publication.

The model is a simulation model (software written in FORTRAN) and it enables to fully reflect of the actual run of the production process with keeping the rules which result from the technology which is used. By using respective algorithms developed by the author, it is possible to model the real process with keeping sequence principle and distance principle. It results in keeping the right order of works in longwall sectors as well as taking into account reciprocal distances e.g. between heading machine and moveable support which depend on permissible surface of uncovered roof.

Modelling of course for separate activities in the longwall is done by using elementary functions of probability densities which are introduced in form of data into the model. The term "elementary" was proposed by the author in order to differentiate these functions from other functions and because these functions describe realisation time in units [minute/meter]. Description of time needed for performing the activity (operation) by the function enables to assess that time including the influence of factors which practically can not be separately determined. There can be listed such factors like e.g. efficiency of mechanical devices, influence of organisation on the course of works in longwall, etc.

The above mentioned opinion was presented in studies made by Centralny Ośrodek Informatyki Górnictwa in Katowice which were carried out in the Ośrodek in the 80-ies. Study (Praca zbiorowa, 1981) can be given as an example. The aim of that study was to determine of time distributions for operation of "dislocation of mechanical support" for different types of the support. In the opinion of the authors of that study, determination of those distributions makes it possible to take into account the influence of non-measurable factors on realisation time of that operation. In my opinion, results which were then obtained were not used in practice because of calculational problems associated with estimation of distribution parameters that, in turn, was associated with not sufficient developed computer technology. Computational problems were also mentioned in conclusion given by the authors of those studies. By using respective algorithms and generating random numbers — according to set functions — the course of works in longwall is modelled. It is worth remembering that every generation of a random number (realisation time) means movement of works, associated with this activity, by 1 meter.

For example, if the random number is generated according to elementary function of probability density which describes work movement of heading machine, it means that within generated time the heading machine moves by 1 meter. After each dislocation, reciprocal distances in the longwall are analysed. When the reciprocal distances are not kept, works which caused that the set distance was exeeded are stopped. For instance, when the maximum distance between heading machine during mining and moveable mechanical support is exeeded then the movement of the heading machine is stopped until the roof has been supported. The idle time of the heading machine is then registerd in the model.

Application in the model of the above mentioned procedures enables to determine the influence of works' courses on the movement of heading machine as well as on time of the whole production cycle.

Further part of this publication presents the study results which were obtained by the author within this area of interest.

There were performed calculations which were aimed to determine of the influence of elementary functions of probability densities for chosen activities and operations on time of production cycle. Also, total idle time for heading machine during mining of the wall was registered. Breaks were caused by too slow course of other works.

In the study made by COIG (Praca zbiorowa, 1981), beta distribution was used for describing of the time needed for realisation of the activity. On that base, however, it is not possible to claim that any elementary function of probability density will have the form of beta distribution.

As a result, on the base of analysis of influence of elementary functions of probability densities on the time of production cycle and on total idle time of heading machine, three groups of conditions were developed for which calculations were performed. Those groups of conditions did not take into account distribution types but only their reciprocal relations.

Sample of calculations No. 1

It was assumed in this sample that for each value "a" from the set of positive real numbers, elementary functions met the following group of conditions:

$$\begin{cases} \int\limits_{a}^{+\infty} f_e(t_u)dt_u - \int\limits_{a}^{+\infty} f_e(t_p)dt_p = 0 \\ \int\limits_{a}^{+\infty} f_e(t_p)dt_p - \int\limits_{a}^{+\infty} f_e(t_0)dt_0 = 0, \end{cases} \tag{1}$$

where:

$f_e(t_u)$ — elementary function of probability density for variable T_u — time of mining by heading machine at 1 meter distance,

$f_e(t_p)$ — elementary function of probability density for variable T_p — dislocation time of wall conveyer at 1 meter distance,

$f_e(t_0)$ — elementary function of probability density for variable T_0 — movement time of mechanical support at 1 meter distance.

Identity of elementary functions results from the above given conditions. It is rather theoretical situation. It would be very rare in practice. This situation was introduced into calculations in order to compare it to results obtained from other calculations.

Sample of calculations No. 2 (a, b)

This sample calculation refers to the situation in which for each value "a" from the set of possitive real numbers, elementary functions meet the following conditions:

$$\begin{cases} \int_a^{+\infty} f_e(t_u)dt_u - \int_a^{+\infty} f_e(t_p)dt_p > 0 \\ \int_a^{+\infty} f_e(t_p)dt_p - \int_a^{+\infty} f_e(t_0)dt_0 = 0 \end{cases} \tag{2}$$

Within the scope of the above mentioned conditions, two particular cases were chosen and marked as 2a an 2b. They are presented in Fig. 1.

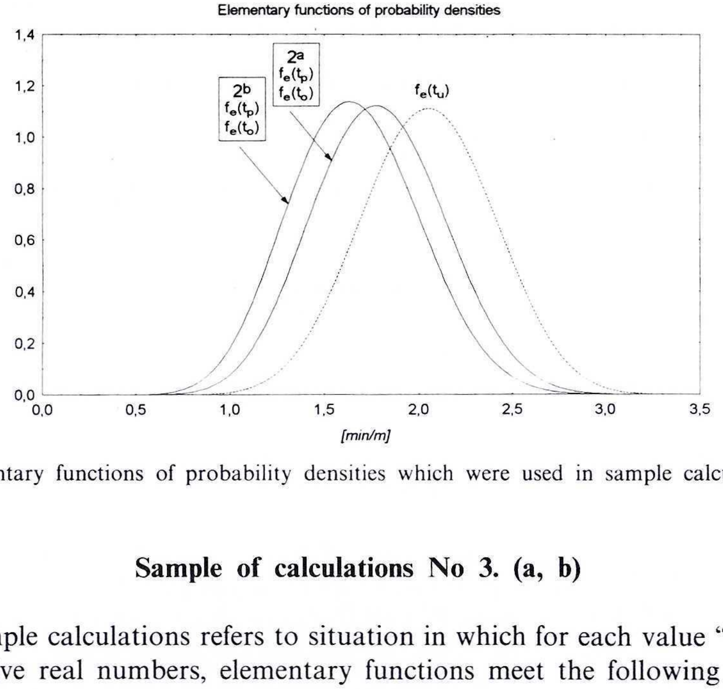

Fig. 1. Elementary functions of probability densities which were used in sample calculation No. 2

Sample of calculations No 3. (a, b)

This sample calculations refers to situation in which for each value "a" from the set of positive real numbers, elementary functions meet the following conditions:

$$\begin{cases} \int_a^{+\infty} f_e(t_u)dt_u - \int_a^{+\infty} f_e(t_p)dt_p < 0 \\ \int_a^{+\infty} f_e(t_p)dt_p - \int_a^{+\infty} f_e(t_0)dt_0 = 0. \end{cases} \tag{3}$$

Within the scope of these conditions, two particular cases were also chosen and marked as 3a and 3b. They are presented in Fig. 2.

Other elementary functions of probability densities with stable courses for all sample calculations are presented in Fig. 3.

Calculations were performed for the longwall which two-way mined by heading machine at lenght 100 meters. The maximum distace between heading machine and moveable support did not exeed 25 meters.

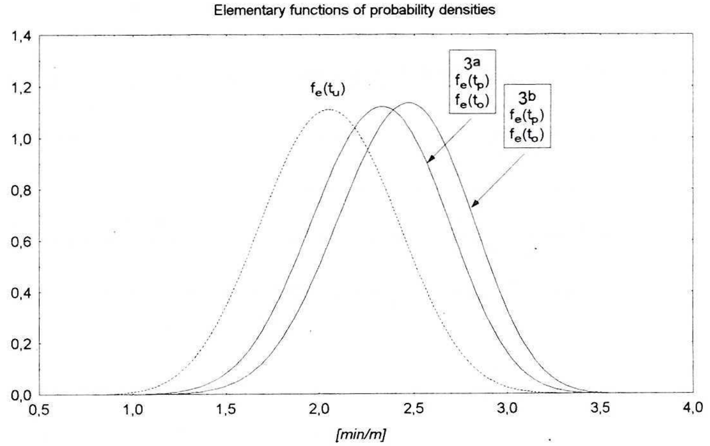

Fig. 2. Elementary functions of probability densities which were used in sample calculation No. 3

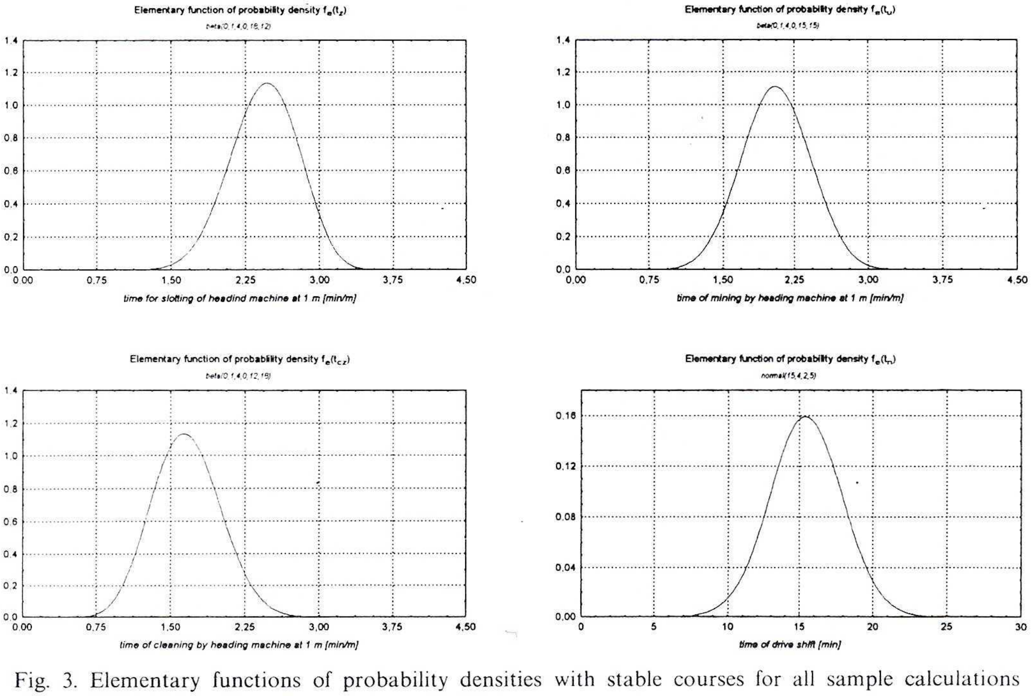

Fig. 3. Elementary functions of probability densities with stable courses for all sample calculations

The size (number) for each sample calculation was set at 740. It resulted from asumptions made by the author and the method described in (Elmaghraby, 1977). The method is based on Kolmogorov-Smirnov test for which it is assumed that the difference between theoretical and empirical distribution functions should not exeed set value D_k for determined value for confidence level α.

The following assumptions were made:

1. Difference between theoretical and empirical distribution functions should not exeed 0.05, i.e. $D_k = 0.05$.

2. Confidence level was set at 0.95, i.e. $\alpha = 0.95$.

For set values D_k and α, value for λ is read from distribution chart for which the following equation is valid:

$$P\left(D_k\sqrt{n} < \lambda\right) = 0{,}95. \tag{4}$$

For value $\lambda = 1.355$ (read from the chart), value for n should be equal at least to 735. On the base of the above given data, the size of the sample was set at $N = 740$. Table shows values for some statistics which were determined on the base of sample calculations.

TABLE

Set of values for statistics which were calculated for results obtained from the sample calculations

		Sample size	Sample calculations				
			2b	2a	1	3a	3b
Duration time of production cycle T_c [min]	Average value	740	279.59	280.54	291.65	303.71	309.96
	Standard deviation		2.87	2.80	2.85	2.89	2.88
Total, average time of breaks in work of heading machine T_{pk} [min]			0.00	0.20	9.80	20.48	26.07

Fig. 4. presents diagrams for functions of probability densities $f_{tc}(t_c)$ for value T_c — duration time of production cycle for sample calculations (positive verification of hypothesis that these functions are normal was made in (Snopkowski, 2000).

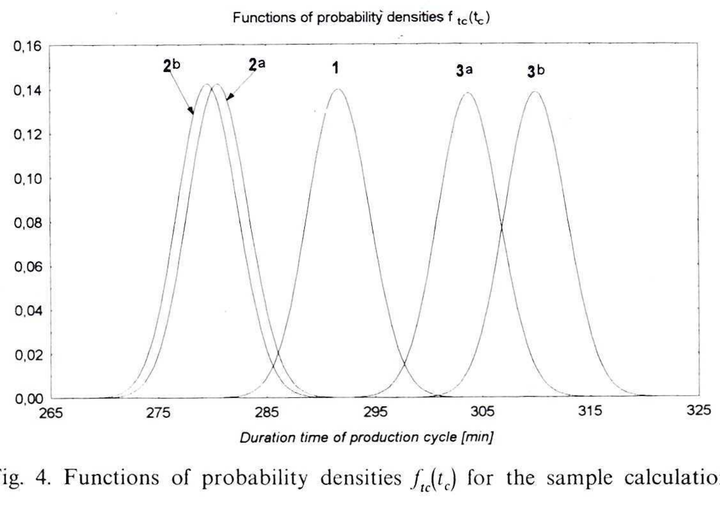

Fig. 4. Functions of probability densities $f_{tc}(t_c)$ for the sample calculations

Interpretation of obtained results leads to conclusion that reciprocal relations between elementary functions of probability densities have substantial influence on the course of function $f_{tc}(t_c)$ for variable T_c — duration time of production cycle. In the sample calculation described by conditions (3), duration time of production cycle becomes longer. The larger the difference which results from inequality in conditions (3), the more unfavourable becomes the situation. It was proved by results of sample calculation 3b. Average total idle time for heading machine work in this sample calculation was 26 minutes. In calculations marked as 2a and 2b the idle time was practically equal to zero.

Conclusions

Determination of relations between elementary functions of probability densities can provide answer for the question whether movement of heading machine can be stopped by other, carried out paralelly (simultaneously) operations of the production cycle.

Therefore, elementary functions of probability densities should meet the following boundary conditions:

$$\begin{cases} \int_a^{+\infty} f_e(t_u)dt_u - \int_a^{+\infty} f_{e_1}(t_1)dt_1 > 0 \\ \int_a^{+\infty} f_e(t_u)dt_u - \int_a^{+\infty} f_{e_2}(t_2)dt_2 > 0 \\ \vdots \quad \vdots \quad \vdots \quad \vdots \\ \int_a^{+\infty} f_e(t_u)dt_u - \int_a^{+\infty} f_{e_i}(t_i)dt_i > 0 \end{cases} \tag{5}$$

for each value "a" > 0,
where:

$f_e(t_u)$ — elementary function of probability density for variable T_u - mining time by heading machine on 1 meter distance,

$f_{e_1}(t_1), f_{e_2}(t_2) \dots f_{e_i}(t_i)$, — elementary functions of probability densities for activities or operations carried out simultaneoulsy (paralelly) with mining by heading machine when realisation of these influence the movement of the heading machine.

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