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MATHEMATICAL MODEL OF A CIRCULAR LATTICE OF PROFILES WITH A VORTEX SOURCE

МАТЕМАТИЧЕСКАЯ МОДЕЛЬ КРУГОВОЙ РЕШЕТКИ ПРОФИЛЕЙ С ВИХРЕИСТОЧНИКОМ




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The articles presents results of a profound comprehensive analysis of dynamics of ventilation performance in dead mine workings as well as the urgency of development of fans for local ventilation with the increased aerodynamic loading and adaptability. A way of adaptation of the conformal transformations method is proposed, using the hydrodynamic analogy principle for calculation of mine radial fans aerodynamics, the impeller blades profiles are presented in the form of segments of logarithmic spirals in a circular lattice. The aim of the work is to construct a mathematical model of aerodynamics of a circular grid of profiles with drain-sources for a purposeful search for ways of increasing the aerodynamic loading and adaptability of mine radial fans. The construction of a mathematical model is based on the principle of hydrodynamic analogy, method of conformal transformations, theory of residues and mathematical theory of singular equations. On basis of the principle of hydrodynamic analogs, the position of critical points of profiles of circular grating and the angle of flow exit from it is determined. A mathematical model is constructed in the form of a system of equations that establish the dependence of aerodynamic loading of shaft radial fan, angle of outflow from its impeller and position of effective critical point of blade profile on the energy characteristics of the source-drain. An original patented technical solution for construction of impeller blades of shaft radial fan is suggested with realization in it of energy flow control method which uses a part of the main fan flow as a source-drain. High potential is shown of the proposed energy flow control method in the inter-blade channels of impeller to increase the operational efficiency, aerodynamic loading and adaptability of mine radial fans

Key words: *fan; circulation; vortex chamber; aerodynamic scheme; vortex source; circular lattice of profiles; circular grid; circulation of stream; unit radius; aerodynamic loading*

Проведен анализ динамики вентиляционных режимов тупиковых выработок шахт. Показана актуальность разработки вентиляторов местного проветривания с повышенной аэродинамической нагруженностью и адаптивностью. Предложен путь адаптации метода конформных преобразований с использованием принципа гидродинамической аналогии для расчета аэродинамики шахтных радиальных вентиляторов, у которых профили лопаток рабочих колес представлены в виде отрезков логарифмических спиралей в круговой решетке. Отмечено, что целью работы является построение математической модели аэродинамики круговой решетки профилей с источниками-стоками для поиска путей повышения аэродинамической нагруженности и адаптивности шахтных радиальных вентиляторов. Построение математической модели осуществлено на базе принципа гидродинамической аналогии, метода конформных преобразований, теории вычетов, математической теории сингулярных уравнений. На основе принципа гидродинамической аналогии установлена зависимость положения критических точек профилей круговой решетки и угла выхода потока из нее. Построена математическая модель в виде системы уравнений, устанавливающих зависимость аэродинамической нагруженности шахтного радиального вентилятора, угла выхода потока из его рабочего колеса и положения эффективной критической точки профиля лопатки от энергетических характеристик источника-стока. Предложено оригинальное запатентованное техническое решение конструкции лопаток рабочего колеса шахтного радиального вентилятора с реализацией в нем энергетического способа управления обтеканием, использующего в качестве источников-стоков часть основного потока вентилятора. Доказана высокая эффективность применения предложенного энергетического метода управления течением в межлопаточных каналах рабочего колеса для повышения эксплуатационной экономичности, аэродинамической нагруженности и адаптивности шахтных радиальных вентиляторов

Ключевые слова: *вентилятор; циркуляция; вихревая камера; аэродинамическая схема; вихреисточник; круговая решетка профилей; круговая решетка; циркуляция потока; единичный радиус; аэродинамическая нагруженность*

Over the last few years significant problems have arisen in the mine ventilation industry due to lacking efficiency of coal mines ventilation.

Technical parameters of local ventilation fans (LVF) do not fully comply with modern requirements for ventilation of blind workings. Increasing load on to stopping face, increasing growth of the length of the blind workings require to use fans with greater aerodynamic loading and adaptability.

The use of profiles with active control over their flow during the design of mine centrifugal fans allows significantly to increase the pressure, developed by them, being very important for gas-sucking fans and local ventilation fans (LVF) which are characterized with high aerodynamic loading [2; 3; 8; 10].

From the practical point of view the most interest is given to circular gratings of piecewise-smooth profiles in which the structural elements of the circular grating itself are used as a source of control jets and the control flow, entering them, is a part of the main flow or the flow of a high-pressure spiral chamber. Such devices are simple in design; they ensure reliability and maintainability of fans, increase of their aerodynamic loading, economy and, as a result, potentially wide area for their application [4; 6].

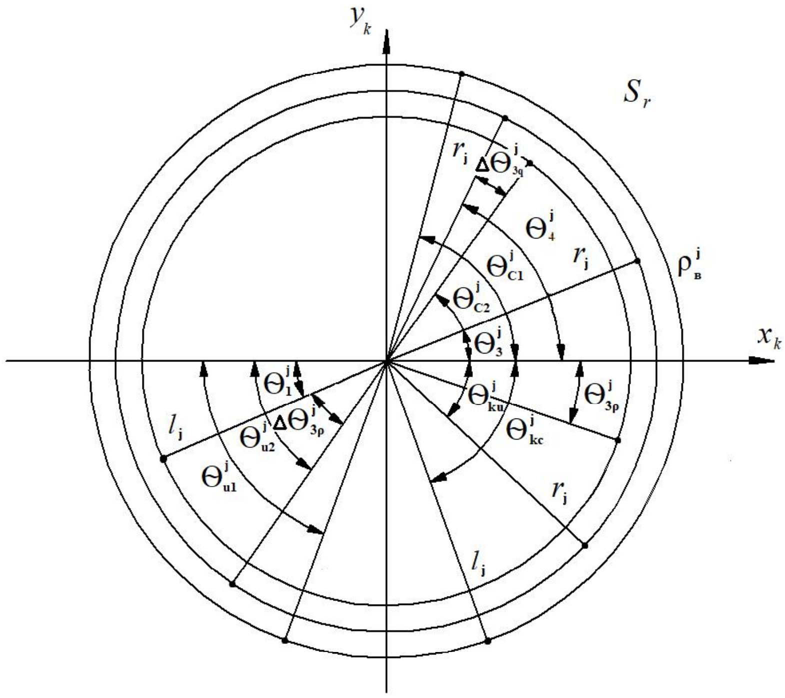
In the theoretical study from the aerodynamic point of view, it is more interesting to study the phenomenon of control flow jetting through the air drainage. In order to build a mathematical model it is necessary to take into account not only the physical process of influencing on the main flow of drainage of the control flow jet but also the complex processes occurring in the boundary layer, the influence of these processes onto the nature of the main stream, flowing around the profile, change in velocities but the main is the amount of additional circulation caused by it and, as a result, the growth of the aerodynamic loading of circular grating of piecewise- smooth profiles [1; 9; 12].

Taking into account that the mathematical model, embracing all these phenomena, is a very complex and inconvenient one, the aim of this article is to determine the cause-effect relationship of changes in the aerodynamic loading of a circular lattice of piecewise-smooth profiles, i.e., change of circulation around profiles, associated solely with the effect onto the main flow of the control flow jet, namely, power characteristics of the source.

The construction of the above mentioned mathematical model is conditioned by the necessity in a simple explanation of reasons for changes in the aerodynamic characteristics of circular gratings with adaptive vortex sources and establishment of position dependence of the rear critical point (RCP) on the parameters of the control flow jet [1; 5; 11].

The study of this phenomenon makes it possible to assess qualitatively and quantitatively the possibilities of the method of improving aerodynamic characteristics, to construct the basic principles and algorithms for designing turbomachines based on them with active methods for controlling of their aerodynamic characteristics.

In figure a model is schematically presented of a circular grating of piecewise-smooth profiles of arbitrary shape with a source of a control flow jet.



Circles of radius $l_j \geq 1$, on which a circular grating of piecewise-smooth profiles with airdrainage is shown, r / Окружности радиусов $l_j \geq 1$, на которых отображена круговая решетка кусочно-гладких профилей со стоками, r

A circle of radius $l_j \geq 1$ with an input channel of an adaptive vortex source defined by coordinates $\theta^j_{c1}, \theta^j_{c2}$ is streamlined by a flow. Physically it means that there is air drainage inside of the circle and a source of the same intensity is located in infinity. A part of the air from the main stream, flowing around the circle, enters it through the above channel. Taking into account that from the point θ^j_{c2} the inflow moves in the direction opposite to the main flow, there is a critical point on the circle guided by a coordinate $\theta^j_к$ in which the velocity of the main stream is 0. Thus, there are three critical points on the circle, i.e. points on the profile of the circular grating in which the rate of the main flow is 0: front critical point θ^j_1, rear critical point θ^j_3, critical point due to the presence of drainage of the vortex source $\theta^j_к$.

In addition, at points determining the width of the input channel of the drainage of the adaptive vortex source $\theta^j_{c1}, \theta^j_{c2}$ and at the beginning of coordinates where the drainage is placed the velocity has infinite value. Thus, accounting the method of Chaplygin S.A. the characteristics and theory of residues, we obtain the equation for the velocity of flow around a circle in the following form:

$$\frac{dP_j}{dr_j} = ql_j e^{-i\theta_3^j} \frac{(r_j - e^{i\theta_4^j})(r_j - e^{i\theta_\kappa^j})(r_j - e^{i\theta_1^j})}{r_j^2 \sqrt{(r_j - e^{i\theta_{c1}^j})(r_j - e^{i\theta_{c2}^j})}}, \quad (1)$$

where $\Delta\theta_{3p}^j = \theta_{3p}^j - \theta_3^j$; P_j – complex potential in the plane of radius $l_j \geq 1$;

$r_j = l_j e^{i\theta_j}$ – complex coordinates of points in the region S_r;

$r_j = t_i^j$ on circles of radius l_j.

Assuming for calculation simplicity $r_j = 1$ the equation (1) is transformed in the following form:

$$\frac{dP_j}{dr_j} = ql_j e^{-i\theta_3^j} \frac{(e^{i\theta^j} - e^{i\theta_4^j})(e^{i\theta^j} - e^{i\theta_\kappa^j})(e^{i\theta^j} - e^{i\theta_1^j})}{e^{2i\theta^j} \sqrt{(e^{i\theta^j} - e^{i\theta_{c1}^j})(e^{i\theta^j} - e^{i\theta_{c2}^j})}}. \quad (2)$$

Taking into account the properties of the complex variable functions the above expressions are transformed in the form:

$$e^{i\theta_3^j} - e^{i\theta_4^j} = e^{i\frac{\theta_3^j+\theta_4^j}{2}} (e^{i\frac{\theta_3^j-\theta_4^j}{2}} - e^{-i\frac{\theta_3^j-\theta_4^j}{2}}) =$$

$$= 2ie^{i\frac{\theta_3^j+\theta_4^j}{2}} Sin\frac{\theta_3^j + \theta_4^j}{2}. \quad (3)$$

After corresponding transformations, taking into account (3.3), we obtain:

$$\frac{dP_j}{dr_j} = -4qe^{-i(\theta_3^j - 0{,}5\theta_4^j - 0{,}5\theta_\kappa^j + 0{,}25\theta_{c1}^j + 0{,}25\theta_{c2}^j + \theta^j)}.$$

$$\cdot \frac{Sin\frac{\theta^j - \theta_4^j}{2} Sin\frac{\theta^j - \theta_\kappa^j}{2} Sin\frac{\theta^j}{2}}{\sqrt{Sin\frac{\theta^j - \theta_{c1}^j}{2} Sin\frac{\theta^j - \theta_{c2}^j}{2}}}. \quad (4)$$

The resulting equation allows to calculate the velocity at any point of the circle of the region S_r that is, to determine the value of the flow circulation.

The velocity modulus according to equation (3.4) is determined by the formula:

$$|V| = 4q \frac{\left| Sin\frac{\theta^j - \theta_4^j}{2} Sin\frac{\theta^j - \theta_\kappa^j}{2} Sin\frac{\theta_j}{2} \right|}{\sqrt{Sin\frac{\theta^j - {}_{c1}^j}{2} Sin\frac{\theta^j - \theta_{c2}^j}{2}}}. \quad (5)$$

The angle of the vector velocity in relation to the X-axis absciss, which determines the position of effective rear critical point (RCP) and characterizes the flow regime around the circle of a unit radius reflecting the flow in a circular grating of piecewise-smooth profiles is expressed by:

$$\bar{\theta}^j = \theta_3^j - 0{,}5\theta_4^j - 0{,}5\theta_\kappa^j + 0{,}25\theta_{c1}^j + 0{,}25\theta_{c2}^j + \theta^j$$

$$\text{If}: \ \bar{\theta}^j = \theta^j - \frac{\pi}{2}. \quad (6)$$

Taking into account that the obtained formulas allow to calculate the magnitude and direction of the velocity at any point of the circle of the unit radius of the region S_r after corresponding transformations, we obtain equations for calculating the position of the effective rear critical point on the circle of the unit radius in the region S_r:

$$\theta_4^j = \theta_3^j - \theta_\kappa^j + \theta_c^j = \theta_3^j + \Delta\theta_\kappa^j, \quad (7)$$

where $\theta_c^j = 0{,}5\theta_{c1}^j + 0{,}5\theta_{c2}^j$ – the angle determining the position of the middle of the input channel of the vortex source;

$\Delta\theta_\kappa^j = \theta_c^j - \theta_\kappa^j$ – angle of displacement of the rear geometric critical point, i.e., angle between the effective (aerodynamic and geometric rear critical points of a piecewise-smooth profile with an adaptive vortex source).

Since, according to Zhukovsky-Chaplygin-Kutt hypothesis the position of the rear critical point, i.e., the point of the air flows cape from the profile, determines the amount of circulation around the profile and consequently the aerodynamic loading of the circular gratings of the profiles; the magnitude of the displacement angle $\Delta\theta_\kappa^j$ determines the value of circulation growth and consequently the aerodynamic loading of the circular lattice of the profiles.

Thus, using the simplest transformations the formula was obtained allowing to explain the physical process of changing the circulation around the profile and as a result the changes in the aerodynamic loading of the circular gratings of the profiles under the influence onto the main air drainage of the control flow jet.

Conclusions.

1. The parameters of the jet drainage of the control flow affect the position of their RCPs of circular gratings of piecewise -smooth profiles.

2. The aerodynamic characteristics and adaptability of fans created on the basis of circular gratings of piecewise-smooth profiles with drains of the control flow depend on their parameters.

3. The purposeful management of the parameters of the jet drainage of the control flow in blades of the fans impellers contributes to the increase of their functional and economic efficiency.

4. With the given intensity of the jet drain of the control flow, a decrease in the width of the outlet channel, resulting in the velocity increase of the drain flow, gives a greater effect of the developed pressure increase.

5. The additional circulation created by the control flow jet allows to use the proposed method of increasing the differential pressure to develop the design of hydrodynamic injectors of effective dust suppression. Promoting effective discharging in the region between a rotating drop of liquid flowing out from the hydrodynamic nozzle and dust particles, it is possible to increase the efficiency of not only dust capture but its absorption at much lower energy levels, in this way, helping to reduce the effective angle of wettability. This is very expedient for dedusting of the media having chemical composition with weak adhesion properties.

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