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Energy Processes of Self-Organization of Vortex Structures in the Problem of Compressor Stability

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ABSTRACT

The extended micro- and macroscopic model of laminar and stationary non-equilibrium turbulent processes of gas motion, which includes cascade cooperative processes of molecules energy self-organization, is suggested here. The model is based on the energy conservation law taking into account the fact that emission and absorption of energy are occurring during change of phases. Potential energy of thermodynamic potential of gas layers velocities difference is transformed into gas molecules rotational motion by overcoming the dynamic viscosity of laminar movement process as a result of the first self-organizing process and non-equilibrium phase change on micro-level. The second process of self-organization phase, which leads to the macroscopic dynamic spiral-vortex structure formation, is initiated when the heat conduction parameter (energy flux density) has reached its critical value.

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Actuality. The problem statement

Turbulence is one of the most complicated natural phenomena connected with emergence and progress of organized dissipative turbulent structures at the specific air flow ratings (regimes), for example, in gas turbine engine (GTE) compressor, which may be considered as non-equilibrium open system. In spite of advances in theoretical and experimental research of this natural phenomenon a lot of main thermodynamic parameters functional relations are unexplored as yet [1, 2]. In particular, they are: gas flow parameters in compressor blade-to-blade channel, which lead to rotating stall; the conditions of turbulent vortex formation, its progress and life time; the conditions of turbulent vortex degradation and breakage (surge). According to traditional thinking turbulence is chaotic process. Nevertheless, there is another point of view first expressed by I. Prigozhinand proved by Yu. L. Klimontovich[3]. Ex hypothesi the transition from the laminar flux to the turbulent one is self-organization process, during of which a part of energy of thermal chaos (connected with arbitrary fluctuations running at molecular level) transfers into binding energy of micro- and macroscopically organized motion of ordered structures. These processes rise the internal system orderliness in comparison with molecular chaos. In particular, the cascade process of vortex formation, which takes place in fully developed turbulence, may be interpreted as the sequence of energetic processes of self-organization. At the same time the set of spatio-temporal scales, within of which this process is progressing, meet the coherent behaviour of molecules of medium. This behaviour is expressed in the form of similar super molecular organization, within of which molecules take part in collective, coherent and interdependent rotational motions. Actuality of the suggested work is defined by the fact that although about 30 years passed since the moment when understanding came that synergetic nature of turbulence is the self-organization process notion concerning coherent structures forming in flow has not been materialized till now into modelling approaches developments directed to the creation of practical engineering methods of turbulence analysis, which would be traditionally based on averaged gas-dynamic equations [4].So, the purpose of given work is: to suggest for discussion the extended phenomenological micro- and macroscopic model of stationary non-equilibrium turbulence including nonlinear cooperative energetic processes of self-organization, which take place in it. It is necessary to detect main contradiction of modern theory and practice in natural turbulization process analysis. In accordance with modern methodology of natural object functioning analysis the contradiction lies in traditional deterministic approach, information inadequacy of which is proved by numerous attempts to develop mathematical and phenomenological models of turbulent flow. In 1986 Sir James Lighthill, who later became a president of International Union of Pure and Applied Mathematics, made a declaration [5]. In the name of his colleagues he apologized for "…educated audience had been misleading during three centuries by determinism apology grounded on Newton's system whereas from 1960, at least, it could be considered as proved that this determinism was erroneous position". It is proved nowadays that energy-informational functioning of evolving natural objects is determined by nonlinear stochastic spatio-temporal dissipative processes[5]. The investigation method grounded on the assertion that nonlinear spatially-temporal transformations occur in stationary non-equilibrium turbulence as a result of a sequence of

cooperative mechanisms of self-organization and energy exchange in the process of micro- and macroscopic nonequilibrium phase changes[4].

The analytical model of energy exchange in gas flow

Let us consider the classical problem of gas flowing through a circular tube having smooth and not heat conductive walls. When gas flow is laminar one its velocity at a tube cross section changes according to Poiseuille parabolic law:

$$v(r) = v_0\left(1-\frac{r^2}{R^2}\right), \qquad (1)$$

where R is the tube radius, v_0 is gas velocity at the tube axis estimated as $v_0 = \frac{P_1 - P_2}{4\eta l}R^2$ $E_0 = (P_1 - P_2) =$ cost is the thermodynamic potential of pressure values difference at the tube ends,

l is the tube length and η is dynamic viscosity of gas.

Laminar gas motion

Let us consider the physical sense of dynamic viscosity parameter. From the classic point of view viscosity is defined as the parameter, which characterizes internal friction, and according to SI viscosity unit is $\left[\frac{N}{m^2}\times s\right]$. In order to reveal energy relationships we convert dynamic viscosity unit in the following way:

$$\left[\frac{N}{m^2}\times s\right] = \left[\frac{kg\times m}{s^2}\times\frac{s}{m^2}\times\frac{m}{m}\right] = \left[\frac{kg\times m}{s^2}\times\frac{1}{m^2}\times\frac{s}{m}\right] = \left[\frac{J}{m^2}\times\frac{1}{v}\right]$$

We obtain that it is possible to define η^E energy parameter of dynamic viscosity (with E upper index) as the parameter of E energy absorption process running over unit of S flow area, which is parallel to v velocity vector:

$$\eta^E = \frac{\partial\vec{E}_S}{\partial\vec{v}}\bigg|_{\Delta r\to 0}, \left[\frac{J}{m^2}\times\frac{1}{v}\right]. \qquad (2)$$

where $\vec{E}_S$ is Umov's vector (energy flux density). It is possible to define viscosity in the energy sense as the parameter of E_0 energy thermodynamic potential specific absorption during gas flow velocity (1) changing. For example [7], nitrogen dynamic viscosity will equal $v_0 = \frac{P_1 - P_2}{4\eta l}R^2$, at the temperature T = 20°C and pressure $P = 101{,}3\frac{kN}{m^2}$ The last means that $E_S\left[\frac{J}{m^2}\right]$ energy flux density of E_0 [J] thermodynamic potential absorption by gas molecules internal energy will increase on the value of ΔE_S = 0,0175J per every 1 m^2 of the cylinder area during the increasing of gas velocity on the value of v =1 [m/s] on the element of cylinder at the tube axial section. Taking into account (1) we get as a result $\Delta E_s = \eta^E \Delta v$ maximal energy flux density (2) close to the tube wall.

Natural question arises about phase processes [4], following of which energy absorption takes place. This problem was considered already when we were determining sound velocity value in gaseous mediums [8]. We shall supplement gas molecule microscopic model with the analysis of nonlinear cooperative processes of self-organization, which take place in it.

Energy analysis. Basing on the obvious fact of E_0 energy absorption by gas molecules in the tube, which is explained by the dynamic viscosity traditional property, we shall do approximation in the form of analysis of $\frac{\langle v_x\rangle}{\langle v\rangle}$ relationship, where ⟨vx⟩ is the rate of gas molecule angular momentum transfer on x axis of the energy transmission channel and ⟨v⟩ is root-mean-square velocity of gas molecules.

In accordance with the first law of thermodynamics $E_1(t)$ thermodynamic potential (internal energy) of the substance, which transfers E_0 energy by the method of $\vec{K} = m_m\vec{v}$ momentum transfer of elementary carriers, is determined as the sum of $E_0(t) = E_1(t) + E_{in}(t)$, where $E_{in}(t)$ is carriers internal energy of stochastic motion in the "empty" energy transfer channel at the temperature of T_0° According to R. Feynman [9, p. 164] who has proved that $\langle v_x\rangle^2 = \frac{\gamma}{3}\langle v_0\rangle^2$ we shall represent the mass of V unit volume of gas transferring $E_1(t)$ energy in the form of $m = \rho_1(x, t)V$ and obtain:

$$E_0 = \frac{\rho_1(x,t)V\langle v_1\rangle^2}{2} > \frac{\rho_0(x,t)V\langle v^2\rangle}{2}, \qquad (3)$$

where $\rho_0(x, t)$ is substance density within unit volume in the channel without $E_{in}(t) = \frac{\rho_0(x,t)V\langle v\rangle^2}{2}$ energy. Taking into account that $\langle v_x\rangle^2 = \frac{\gamma}{3}\langle v_0\rangle^2$ we obtain:

$$\rho_1(x,t)V\left(\frac{\gamma}{3}\right)\langle v\rangle^2 > \rho_0(x,t)V\langle v\rangle^2 \qquad (4)$$

We may conclude that during the process of $E_0(t)$ energy introducing into the transmission channel the inequality

$$\rho_1(x,t) > \frac{3}{\gamma}\rho_0(x,t) \qquad (5)$$

must be kept for the density parameter of the substance in this channel. (3 – 5) analysis allows make the conclusion about the fact of spasmodic ρ(x, t) density parameter change on the coefficient value of $\frac{3}{\gamma}$ during $E_0(t)$ energy introducing into the channel.

Let us make the analysis of gas molecule energy change at T^0 =const which transfers the momentum of $\vec{K}(x, \Delta t) = m_m\langle\vec{v}1\rangle(x, \Delta t)$, where Δt is the time of gas molecule free path on x axis of the channel and $\langle\vec{v}1\rangle$ is the velocity, which is additionally introduced by $E_0(t)$ energy and averaged within Δt time interval. It is necessary to note that the problem statement itself contains the internal contradiction of traditional model because of the velocity increasing on the $\langle\vec{v}_1\rangle$ value gives total molecules velocity on x axis, which equals $\langle\vec{v}_1\rangle + \langle\vec{v}\rangle$. This circumstance involves the increasing of T_0 substance temperature in the channel that contradicts to both Laplas' principles of heat potential constancy and experimental research results.

As provided by the law of energy equipartition according to degrees of freedom the energy quantity of 1/2 kT^0 falls on every degree of freedom (on z,y,x axes). Let us write (3) relationship for falls on every degree of freedom (on z,y,x axes). Let us write (3) relationship for $\langle v_{1_x}\rangle^2 = \frac{\gamma p(x,t)V}{\rho_1(x,t)V}$ analogy with the analysis carried out by Feynman [9, p. 162]. We obtain $\langle v_{1_x}\rangle^2 = \frac{\gamma NkT^0}{Nm_m} = \frac{\gamma kT^0}{m_m}$ including that $p(x, t)V = Nm_m$ is mass of gas. It follows that E_m molecule energy, which absorbs a part of E_0 energy, is determined as:

$$E_m = \frac{m_m v_{1x}^2}{2} = \frac{\gamma}{2} kT^0,$$
$$2 > \gamma > 1, \qquad (6)$$
$$\frac{3}{2} kT^0 > E_m > \frac{1}{2} kT^0$$

And again, there is the contradiction here, which assumes that decreasing of T^0 temperature of channel unit volume takes place and it brings ⟨v⟩ velocity decreasing or energy distribution change according to fractional number of degrees of freedom. In fact, we watch consistency of temperature, so, it is necessary to analyze the process of change of degrees of freedom number parameter, integer change of which is explained by energy change of substance unit volume. We may conclude that energy insertion into a gas volume in the tube will change the number of degrees of freedom of some molecules aggregate transferring E_0 energy of thermodynamic potential.

Energy transferring process $E_0(t, \Delta t) = \text{const}$, $t \in [\Delta t]$ initiates non-equilibrium micro-level phase change, which changes parameters of motion of the molecules having some gas mass of m (this mass determines) $E_0(t, \Delta t)$ energy) on x, y and z axes. The self-organization process takes place, which joins energy) on x, y and z axes. The self-organization process takes place, which joins $\langle \vec{v}_{x,y,z} \rangle$ velocity vectors of thermal motion in such a way that when molecules are changing their inertia moment (order parameter) they begin transfer the angular momentum $\langle \vec{M}_m(x,y,z) \rangle = m_m \langle \vec{v} \rangle \langle \vec{r} \rangle$ towards E_0 thermodynamic potential gradient. In the z,y plane $\vec{K}(y, z)$ momentum vectors are joined into single $\vec{M}_{y,z}(\omega_x, t)$ momentum vectors are joined into single angular momentum vector, which rotates $\langle \vec{\omega} x \rangle$ (and with $\langle \vec{v}_{y,z} \rangle$ linear velocity) determining $E_\omega(t, \Delta t)$ molecule rotational motion energy. As a result of continuous process of electrons guide-path coordinates change in accordance with their rotational number the alteration of degrees of freedom number of substance molecule in transmission channel takes place. Guide-paths change leads to degrees of freedom number decreasing and to the molecule order parameter change: from the point to symmetry axis. Here are the integrating relationships, which take into account the law of conservation of energy and meet the condition of equally probable distribution of energy according to the degrees of freedom:

$$\langle E_0(t, \Delta t) \rangle = \text{const}, t \in [\Delta t],$$
$$\langle E_0(t, \Delta t) \rangle = \langle E_{v_x}(t, \Delta t) \rangle + \langle E_{\omega_{y,z}}(t, \Delta t) \rangle,$$
$$0.5 \langle E_{v_x}(t, \Delta t) \rangle = m \langle v_x(t, \Delta t) \rangle^2, \qquad (7)$$
$$0.5 \langle E_{\omega_{y,z}}(t, \Delta t) \rangle = J_x(t, \Delta t) \langle \omega_x(t, \Delta t) \rangle^2$$

Quantitative analysis of energy of gas molecules rotational motion

Let us consider molecules rotation assuming that there is rigid constraint between atoms [7], i.e. ignoring fluctuations. Relatively to the axis, which is perpendicular to molecule axis and passes through inertia center, inertia moment equals $I = 2M_{pr} R^2_0$ for diatomic molecule where M_{pr} is adjusted inertia moment and R_0 is molecule radius. Energy of rotational motion is connected with M molecule rotational angular momentum as Eω $E_\omega = \frac{\vec{M}^2}{2I}$

This last may be quantized as $M = \hbar\sqrt{J(J+1)}$, where J=0,1,2... is rotation number and ħ Planck's constant. Thereby we can determine rotational energy levels:

$$E_\omega = \frac{\hbar^2}{2I}\sqrt{J(J+1)}, J = 0,1,2\ldots . \qquad (8)$$

Changes from $\Delta J = \pm 1$ are allowed for rotational spectrum, i.e. absorption or emission of quantum with energy of $\Delta E_\omega = 2(\hbar^2/2I)$ may take place.

Constant (under $T^0 = \text{const}$ condition) momentum transfer rate of $\vec{K}_{x,y,z}(m, \langle \vec{v} \rangle, t)$ is the uniting energy parameter and in accordance with Fermat's principle it must meet $\langle \vec{v} \rangle$ mean-root-square velocity of substance molecules in the energy transfer channel.

Heat conduction (volume density of Es energy flux) of every gas type is invariable within Δt time interval and it can be determined by γ (t, Δt) adiabatic constant. The conditions of formation of molecules angular velocity vectors are:

$$\varphi_v(t, \Delta t) = \arccos\left[\frac{1}{\gamma(t, \Delta t)}\right]$$
$$\vec{v}_x(t, \Delta t) = \vec{v}(t, \Delta t)\cos[\varphi_v(t, \Delta t)], \qquad (9)$$
$$\vec{v}_{y,z}(t, \Delta t) = \vec{v}(t, \Delta t)\sin[\varphi_v(t, \Delta t)]$$

where $\varphi_v(t, \Delta t)$ parameter is the angle between $\vec{v}_x(t, \Delta t)$ and $\vec{v}(t, \Delta t)$ vectors of the substance molecules motion rates in the transfer channel and $\vec{v}_{yz}(t, \Delta t)$ is linear molecules velocity.

The proof of suggested model and its connection with natural processes and the fundamental researches, which were carried out earlier, are presented in [8].

Molecule electromagnetic properties after microscopic non-equilibrium phase change

A molecule is neutral in the "empty" channel and it has no external electric and magnetic fields that would be compensated by the shell forming by electrons, which rotate in neutral orbits. The exchange of electrons orbits parameters occurs in accordance with the rotational number after endothermic phase change (8). As a result electromagnetic neutrality has been broken and a molecule gains the property of electromagnetic dipole with q_e charge. Strength of $\vec{E}_e$ electric field and induction of $\vec{B}$ magnetic field are described by Maxwell equations, which may be considered in general view as electromagnetic equations of thermodynamic of non-equilibrium processes [10]:

$$\text{rot}\vec{B} = \frac{1}{c}\frac{\partial \vec{E}_e}{\partial t} + \frac{4\pi}{c}\vec{j}$$
$$\text{rot}\vec{E}_e = -\frac{1}{c}\frac{\partial \vec{B}}{\partial t}, \qquad (10)$$
$$\text{div}\vec{E}_e = 4\pi q_e$$
$$\text{div}\vec{B} = 0$$

where c is light speed. The first equation expresses Ampere's law including j current offset, the second one – electromagnetic induction law, the third one – Coulomb's law, the fourth one determines the vortex magnetic field without an issue and drain. Electromagnetic field is characterized by $\vec{E}_s = \vec{E}_e \times \vec{B}$ energy-flux density, i.e. by Poynting vector.

Lorentz generalized force of $\vec{F}_L = q_e\vec{E}_{eex} + q[\vec{v}_x \times \vec{B}_{ex}]$ acts on the molecules moving in Earth's magnetic field. Here $\vec{E}_{eex}$

and $\vec{B}_{ex}$ are Earth's field strength and induction, respectively. Lorentz force determines the spiral path of molecules motion. It is necessary to notice that under laminar gas flowing (when Reynolds' number is small) the distances between "energetic" molecules-dipoles are so large that the forces, which are determined by Coulomb's law as $F = \frac{1}{4\pi\varepsilon_0}\frac{q_{e1}q_{e2}}{r_{12}^2}$, are small and do not significantly effect on the motion paths. Direction of velocity vectors (9), as well as electric and magnetic fields vectors (10), is incoherent one and determined by environmental potentials and fields.

Electromagnetic properties of turbulent vortices of a rotating stall is indirectly corroborated by positive results of experimental research [11] of the problem how high-voltage electric field generated by plasma actuator electrodes, which are placed between stator blades, effects on compressor stability.

The facts of electrification of some materials, as well as lightning generation in the clouds or erosion marks on GTE rotor bearings, are indirect proof of electromagnetic nature of friction energy absorption.

Summary about laminar motion. 1. As a result of microscopic non-equilibrium phase change the energy of external thermodynamic potential is absorbed by the energy of molecules rotational motion (8) in the process of dynamic viscosity overcoming (2). Lorentz forces determine the spiral path of molecules motion.

2.Energy of the molecules (7), which are in non-equilibrium state, is determined by the rotational number.

3."Energetic" molecules gain the properties of electromagnetic dipole with the parameters of (10) and they are concentrated in the near-wall region where $\left(\frac{\partial v}{\partial r}\right) \to \max$.

Gas-dynamic instability and turbulence occurrence

As E_0 thermodynamic potential increases v_0 velocity grows, too. We are interested in v_1 velocity value and its gradient in the near-wall region first of all because of there is the maximal concentration of "energetic" (7, 8) molecules-dipoles having electromagnetic field (10) within that flow volume. Simultaneously $Re = \frac{\rho v_1 l}{\eta}$ Reynolds' number is growing, here ρ is gas density $\left[\frac{kg}{m^3}\right]$ and l is the tube length [m]. In order to reveal the energy relationship Reynolds' number unity [5] may be converted by analogy with dynamic viscosity in the following way:

$$\left[\frac{\left[\frac{kg}{m^3}\right]\left[\frac{m}{s}\right][m]}{\left[\frac{N}{m^2}\times s\right]}\right] = \left[\frac{\left[\frac{kg}{m^3}\right]\left[\frac{m}{s}\right][m]}{\left[\frac{kg\times m}{s^2}\frac{1}{m^2}\times s\right]}\right] = \left[\frac{\left[\frac{kg\times m^2}{s^2}\right]\left[\frac{1}{m^3}\right][m]}{\left[\frac{kg\times m}{s^2}\frac{1}{m^2}\right][m]}\right] = \left[\frac{\left[\frac{kg\times m^2}{s^2}\right]\left[\frac{1}{m^2}\right]}{\left[\frac{kg\times m^2}{s^2}\right]\left[\frac{1}{m^2}\right]}\right]$$

We obtain that it is possible to determine energy parameter of Reynolds' number (E upper index) as the ratio of E_S energy flux density of the gas having v_1 velocity to some energy density in undisturbed gas flow, i.e. at v=0:

$$Re^E = \frac{E_S|_{v=v_1}}{E_S|_{v=0}}. \qquad (11)$$

The relationship (11) shows how many times energy flux density increases in laminar gas flow under condition of flow velocity increasing from zero to v_1.

It is known that when Reynolds' number achieves its Re^E_{kr} critical value the process of flow turbulization has launched. Taking into account the hypothesis suggested for laminar flow we can assume that in this moment (at $Re^E = Re^E_{kr}$) such a volume density of "energetic" molecules is reached that Coulomb's forces have become equal to (or larger than) inertia forces. "Energetic" molecules begin to form space structures [10], within of which macroscopic endothermic non-equilibrium phase change takes place. The physical reason of the change is as follows.

While E_0 thermodynamic potential increases gas flow velocity is growing, too. Thereby the larger mass flow capacity value relating to E_S energy flow density parameter is required than that, which could be provided by the tube geometric dimensions and heat conduction parameter. Majority of molecules absorbed energy (1, 8) of thermodynamic potential within near-wall flow volume and have gained the properties of electromagnetic dipole (10). In order to increase abovementioned capacity molecules are self-organizing by means of endothermic collective coherent union of electromagnetic fields (10), under which the more ordered spiral motion – the vortex moving in the near-wall region – has occurred. Energy capacity (energy flow density) of linear and spiral-rotational motion of the vortex structure is considerably larger than of the laminar one:

$$\begin{aligned}
&\langle E_W(t)\rangle \neq \text{const},\\
&\langle E_W(t)\rangle = \langle E_{v_x}(t)\rangle + \langle E_{\omega_{y,z}}(t)\rangle,\\
&\langle E_{v_x}(t)\rangle = m\langle v_x(t)\rangle^2,\\
&\langle E_{\omega_{y,z}}(t)\rangle = J_x(t)\langle \omega_x(t)\rangle^2
\end{aligned} \qquad (12)$$

This is explained by the fact of difference between viscosity coefficient (2) values: in the vortex of fully developed turbulence and in laminar gas flow.

Positive feedback determines the dynamics of growth, form and stability of vortex by its internal gradient of thermodynamic potential, which includes difference of temperature and pressure, and by its internal electromagnetic field:

$$\begin{aligned}
&\vec{E}_{W0}(t) < \vec{E}_0(t)\\
&\text{div}\vec{E}_e < 0\\
&\text{div}\vec{B}_1 < 0
\end{aligned}, \qquad (13)$$

This field is coherent superposition of molecules fields (10). Besides mechanical field, equations (13) determine vortex magnetic and electric fields, which have the drain of external field. In other words, these fields absorb E_0 energy of external thermodynamic potential and describe vortex expansion tendency. Internal concentration of vortex electromagnetic and mechanical energy (12, 13) creates internal gradient of $\vec{E}_{W0}(t) = E_0(t)$ thermodynamic potential. rotv rotor vector of Ω_v vortex angular velocity is oriented towards the vector of the sum of gradients vectors of internal and external thermodynamic potentials and fields.

During gas vortex experimental research [12] (for mole concentrations of $\alpha(N_2) = 0{,}8$ and $\alpha(O_2) = 0{,}2$) and in case of high level of turbulization the turbulent viscosity value was at the

nozzle exit section ≈ 2500 times as much as laminar viscosity. This value is of the same order as critical Reynolds' number, so, this fact indirectly corroborates expressions (11, 12). In case of low level of turbulization when turbulent flow is considerably less than laminar one the viscosity value (2) was five times less than the laminar one. This fact corroborates more extensive energy properties of vortex and determines availability of the part with $\frac{\partial E_0}{\partial Q}$ negative differential internal resistance, where Q is gas flow value, or with so called S-characteristic on the loading map of compressor.

The effect of negative internal resistance (hyperconductivity) occurrence is connected with termination of the process of external thermodynamic potential energy (2) absorbing by near-wall region molecules. Differential resistance of this region decreases and is determined by molecules velocity fluctuations. Viscosity (2) decreases and velocities (12) increase when the vortex separates from the wall that is explained by the law of momentum conservation.

Semiconductors, in particular, thyristors, dynistors and tunnel diodes have similar S-voltage-current characteristics. We may conclude that the tunnel effect of negative differential internal resistance of energy transfer channel is inherent to the processes, which complete saturation of the molecules within near-wall region by energy and launch macroscopic collective electromagnetic fields union of energy carriers electromagnetic fields. We may expect that compressor stage energy effectiveness would be maximal one if its operating point is in the "saddle" (in local extremum) of S- characteristic.

It is universally recognized that turbulent vortex analytical representation is the subject of individual research and in this connection let us consider its key properties followed from foregoing analysis.

Summary about turbulent motion

1. A vortex is macroscopic endothermic dynamic structure, within of which the concentration of vortex electromagnetic and mechanical energy creates internal gradient of thermodynamic potential.

2.Internal gradient of thermodynamic potential and internal electromagnetic field characterize energy parameters of a vortex and determine its form, stability and the property of its expansion. The gradient value determines energy absorption rate parameter and, respectively, the moment of the beginning of surging visualization. In other words, this is the moment when vortex diameter reaches the size of blade channel, when the vortex is discharged into stator blade channel. Also this is the moment when exothermic destruction of the vortex and changes of operating point parameters on compressor S-characteristic take place.

3.Non-compliance with non-equality (13) leads to degradation and destruction of the vortex. In case of vortex destruction along generating line the exothermic phase process is initiated with almost instantaneous absorbed energy release in the form of pressure (temperature) increasing and with the occurrence of potential difference of molecules additive electric field at the breaking point.

Summary

The extended micro- and macroscopic model of laminar and stationary non-equilibrium turbulent mechanism of energy transfer within gaseous mediums based on the cascade cooperative processes of molecules energy self-organization is suggested here. The model is grounded on the energy conservation law taking into account the fact that emission and absorption of energy are occurring during change of phases.

Potential energy of thermodynamic potential of gas layers velocities difference is transformed into energy of gas molecules rotational motion (8) by overcoming the dynamic viscosity of laminar motion process (2) as a result of the first self-organizing process and non-equilibrium phase change at the micro-level. Energy of the molecules (7), which are in non-equilibrium state, is determined by their rotational number. "Energetic" molecules gain the properties of electromagnetic dipole with the parameters of (10) and they are concentrated in the near-wall region. Lorentz force determines the spiral path of their motion.

The second process of self-organization phase, which leads to the macroscopic dynamic spiral-vortex structure formation, is initiated when the heat conduction parameter (energy flux density) has reached its critical value. As a result of non-equilibrium phase change the energy of external thermodynamic potential is absorbed by electromagnetic cohesions and concentrates within the vortex. Vortex moment of inertia determines the rotational motion energy and generally it has no limits. Vortex internal energy (12, 13) creates thermodynamic potential within flow. Electromagnetic field within the vortex has the drain of external field, i.e. it absorbs the energy of external thermodynamic potential and determines the process of vortex extension. rotv rotor vector of Ω_v vortex angular velocity is oriented towards the vector of the sum of gradients vectors of internal and external thermodynamic potentials. Non-compliance with non-equality (13), which is result of external energy influx limitation, leads to degradation and destruction of the vortex.

The results of experimental research of energy transfer in GTE compressor will be presented in the next publications.

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