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Fractal formalism in identification of indoor sports facilities as systems with partial indeterminism

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The paper considers the peculiarities of functioning and management of closed-type sports facilities designed to implement artificial hypoxic training process. For identification of such complex systems models of different types are used depending on the goals set. The complexity of the choice of physical and mathematical models in this case is due to the complexity of the behavior of the systems under consideration at different moments of time, during which their basic properties can change dramatically. The use of the E. Lorentz air carousel allows in this study to *apply the methods of fractal formalism and modeling to describe the behavior of such numerically irreducible systems. An algorithm for determining the self-similarity region for the object under study is given, which, in its turn, makes it possible to reduce the probability of violation of its normal operation mode, namely, maintaining the constancy of static and dynamic components of oxygen partial pressure, proper humidity, speed and direction of air mass flow circulation in the given structure (without using energy-consuming forced ventilation system). The possibilities of application of fractal models and methods of geometrical control theory for identification of complex systems/sports facilities of the closed type functioning in energy-saving modes and intended for artificial hypoxic training are considered.*

It should be noted that for air mass circulation technologies (without the use of forced ventilation) in closed sports facilities for hypoxic training of athletes, the above method of determining the self-similarity region can serve as an analogue of the indicator, which constantly registers the approach of the determining parameter to one of the boundaries of the self-similarity region, thereby signaling the probability of a situation that leads to a sharp change in the direction of circulation of air masses in the building.

Keywords: fractal formalism, identification, sports facilities, systems with partial indeterminism, energy-saving technologies, methods of geometric control theory

Formulation of the problem

Now in different countries of the world there are sports and training centers located in the middle mountains. The largest and better equipped centers are located at altitudes from 1600-1700 m to 2300-2600 m. Conditions of many modern centers allow to use training and living in quite a wide range of altitudes: athletes can live at an altitude of 1800-2500 m and train at an altitude of 2700-3500 m, or vice versa, live at an altitude of 2200-3000 m and train at an altitude of 1000-1200 m, etc. For example, athletes who train at a mid-mountain center in Colorado Springs (USA) have the opportunity to train at an altitude of 1860 m and reside at an altitude of 2750 m in the highlands.

There are many peculiarities of functioning and management of closed-type sports facilities designed to implement artificial hypoxic training process. For identification of such complex systems models of different types are used depending on the goals set. The complexity of the choice of physical and mathematical models in this case is due to the complexity of the behavior of the systems under consideration at different moments of time, during which their basic properties can change dramatically. The use of the E. Lorenz air carousel allows applying the methods of fractal formalism and modeling to describe the behavior of such numerically irreducible systems. An algorithm for determining the self-similarity region for the object under study is known, which, in its turn, makes it possible to reduce the probability of violation of its normal operation mode, namely, maintaining the constancy of static and dynamic components of oxygen partial pressure, proper humidity, speed and direction of air mass flow circulation in the given structure (without using energy-consuming forced ventilation system). There are some possibilities of application of fractal models and methods of geometrical control theory for identification of complex systems/sports facilities of the closed type functioning in energy-saving modes and intended for artificial hypoxic training.

Analysis of the latest publications on the research topic

All the variety of forms of training athletes using an additional hypoxic factor can be divided into two groups [1]: natural hypoxic training (training in mountain conditions) and artificial hypoxic training (training at sea level with the use of special facilities, equipment or methodological techniques that ensure the presence of an additional hypoxic factor). Special studies, as well as the experience of training outstanding athletes in different countries of the world have convincingly shown that the main place in the system of hypoxic training of athletes should be occupied by natural training in the mountains, which causes noticeably more pronounced reactions and effective adaptation compared to hypoxic training in artificially created conditions [1, 2]. At the same time, artificial hypoxic training with its rational planning can successfully complement training in the mountains, eliminating many organizational and methodological shortcomings of the latter [3, 4].

To date, it is difficult to imagine the identification of closed sports facilities of this type due to their extreme complexity, especially if we take into account the processes of heat and mass transfer and the problems of optimal control (with the use of energy-saving technologies) of the movement of air masses constantly circulating in such buildings. Obvious in this case is the need to use mathematical modeling methods. Among all types of mathematical models of modern indoor sports facilities for artificial hypoxic training of athletes as particularly complex systems, a special place is occupied by models in which it is necessary to substantiate its belonging to the fractal type [6-9]. At the same time, we should pay special attention to the fact that such objects at their identification at some moments of time are observed situations in which some components of the system (in particular, circulating in the structure air mass flows, the direction of movement of which is determined by the determining parameter) instantly change the sign of their action to the opposite one. Such a phenomenon is dictated by the global instability of the identification object.

About global instability, which usually leads to numerically irreducible problems of identification of some, as if deterministic objects [10], began to talk intensively after the discovery by E. Lorenz of the so-called "atmospheric merry-go-round", which, for example, leads to unpredictability of weather.

E. Lorenz mathematically described the change of the atmosphere, which is affected by two factors: heating of air from the ground and its cooling in the upper layers. As a result of heating, the air expands and rises upward, displacing the cold air that descends. A kind of "carousel" is formed.

Having made several revolutions in one direction, at some point in time this carousel begins to rotate in another direction, then again changes its direction, etc.

The nature of this phenomenon is quite simple. With large temperature differences, the speed of the air mass will be high and it will not have time to cool down at the top in order to descend, and therefore begins to "float", which will slow down the rotation of this "carousel". As a result, the rotation starts in the other direction, etc. (It is assumed that the occurrence of tornadoes, tornadoes and similar phenomena is subject to similar laws).

The use of the E. Lorenz air carousel allows in this study to apply the methods of fractal formalism and modeling to describe the behavior of such numerically irreducible systems. An algorithm for determining the self-similarity region for the object under study is given, which, in its turn, makes it possible to reduce the probability of violation of its normal operation mode, namely, maintaining the constancy of static and dynamic components of oxygen partial pressure, proper humidity, speed and direction of air mass flow circulation in the given structure (without using energy-consuming forced ventilation system). The possibilities of application of fractal models and methods of geometrical control theory for identification of complex systems/sports facilities of the closed type functioning in energy-saving modes and intended for artificial hypoxic training are considered.

Purpose and objectives of the study. The purpose of the work is to justify the use of methods of the fractal modeling and geometrical control theory for identification of complex systems/sports facilities of the closed type functioning in energy-saving modes and intended for artificial hypoxic training.

Materials and methods

We used such methods: a) methods of the mathematical physics; b) methods of molecular and kinetic theory; c) methods of geometric control theory; d) methods of fractal modeling.

In recent years, much attention has been paid to the introduction of training under conditions of artificially created hypoxia into the process of training athletes. Such training requires special facilities and equipment. For this purpose, bar cameras are used, in which the total air pressure and, consequently, the partial pressure of oxygen are changed; climatic chambers, in which a given hypoxic mixture is supplied. For example, the Olympic training base in Colorado Springs operates a bar camera with a built-in hydro channel for training swimmers (Figure 1). Similar facilities exist at various centers for training runners, cyclists, skiers, rowers, and athletes specializing in other sports.

Each of the forms of artificial hypoxic training that are used in practice (staying in climatic chambers, using masks through which a hypoxic mixture is fed, etc.) and training in climatic chambers, use of masks through which a hypoxic mixture is fed, etc.), has strengths and weaknesses and, of course, cannot replace training in natural mountain conditions.

However, training in artificial hypoxic conditions is a good addition to natural mountain training, which allows to ensure the effective process of acclimatization of athletes in mountain conditions, as well as to maintain the achieved in natural mountain training.

Conditions, as well as to maintain the level of adaptation, achieved in the mountains during the period of subsequent training in the plain conditions.

Artificial hypoxic training is an effective means of accelerating the acclimatization process, especially in cases when training in mountain conditions cannot last for a long time. The use of hypoxic training for several days before moving to the mountains of intense training programs in conditions of artificial hypoxia allows to accelerating significantly the process of adaptation of athletes to mountain conditions and already on the third or fourth day of their stay in the mountains to plan intense training programs.

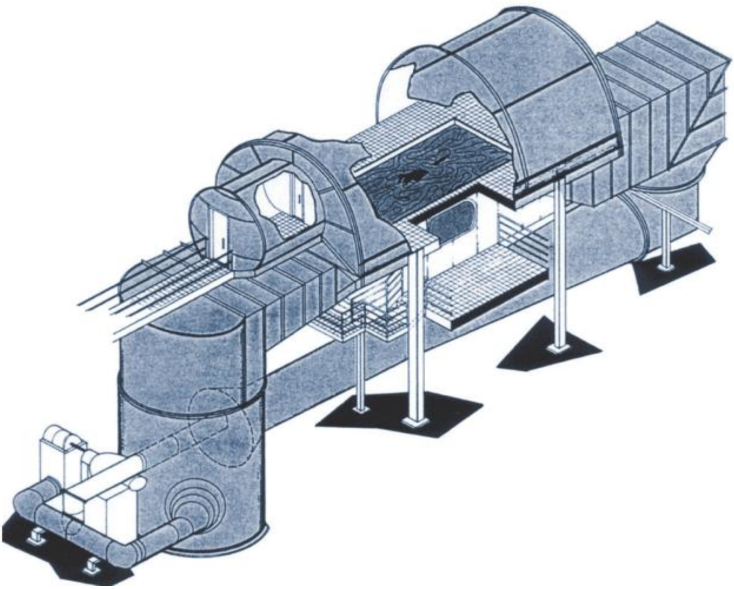

Fig.1. A hydrodynamic pool hyperbaric chamber (schematic), which operates at the U.S. Olympic base in Colorado Springs (General View)

Numerous observations made during training of high-class athletes in different countries of the world have shown that preliminary training in artificial hypoxic conditions allows accelerating the process of acclimatization of athletes on average 2-2.5 times. Athletes, who apply artificial hypoxic training for 5-10 days before going to the mountains, pass the phase of acute acclimatization within

2-3 days. Without such preliminary preparation, training in the mountains with high loads can be started only 5-7 days after moving to the mountains [4].

The minimum amount of preliminary artificial hypoxic training necessary for the subsequent effective mountain adaptation depends on many factors (athlete's specialization, experience of mountain training, nature of previous and subsequent mountain training, and the nature of the mountain adaptation, training, the nature of previous and subsequent training, etc.). The effect is noticeable already in the case when artificial hypoxic training is used for 10 days with a total amount of work in hypoxic conditions of 12-15 hours.

The use of artificial hypoxic training for preliminary adaptation to mountain conditions is especially effective in the case when it is planned to hold training camps in the mountains at an altitude of more than 2000 meters. The height of ascent during training in artificial hypoxia should be planned in accordance with the height of the next mountain training. The time interval between the last training session in conditions of artificial hypoxia and the first training session in the mountains should not exceed 2,000 meters.

Training in the mountains should not exceed three days [3].

If it is necessary to participate in a long series of competitions, the maintenance of the level of fitness is facilitated by the inclusion in the programs of microcycles of classes that are held in conditions of artificial hypoxia and contribute to the maintenance of the previously achieved level of aerobic and anaerobic glycolytic capabilities. The alternation of such sessions with speed, strength, coordination and technical-tactical activities, which are conducted under normal conditions, allows maintaining the level of athletes' readiness for starts for a long time [5].

In the period between the end of mountain training and starts in the main competitions, short-term microcycles (3-6 days) with an increased volume of hypoxic training in artificial conditions can be included, which will allow to maintain the level of adaptation achieved by training in the mountains. An important point in the inclusion of training with artificial hypoxic conditions is the possibility to alternate work on the development of aerobic and anaerobic glycolytic capabilities in hypoxia with training in normal conditions, which contributes to the improvement of other aspects of fitness, work on which is contraindicated in hypoxia.

New in our research

The Lorenz carousel effect is inherent in many technologies. If one fix the moments of time when the direction of rotation of this "carousel" changes, he will get a random sequence of numbers. In particular, in the above-mentioned closed-type sports facilities (swimming pools) designed for artificial hypoxic training, the mobility/velocity of air near the water surface should be minimal (V=0.05 m/s). Increased mobility leads to a significant increase in water evaporation, deterioration of relative humidity control and increased energy consumption by the ventilation system. The air velocity at the floor of the room around the pool should be within V=0.13 m/s so that swimmers do not experience unpleasant cooling sensations due to evaporation. In the upper part (at the ceiling of the pool), the speed of air masses can be higher due to the operation of specially equipped forced ventilation, which, incidentally, operates, as a rule, far from energy-saving (and, therefore, excessively energy-consuming) modes.

In connection with the above-mentioned, to investigate the possibility of the E. Lorenz carousel occurrence in the air masses of a swimming pool (as objects of identification of indoor sports facilities for artificial hypoxic training), the algorithms of application of fractal formalism are given below. It is this formalism, according to the authors of this paper, which is able to identify objects and systems with partial indeterminism.

The components of the determining parameter can be chosen as the velocity of the air mass and its temperature, after which the self-similarity region is defined as the constancy of the ratio of these components. However, it is necessary (!) to take into account the necessity of keeping constant the value of oxygen partial pressure (O_2) (its static and dynamic components), especially in conditions of artificial hypoxia. Maintaining a constant value of the latter parameter is possible by special regulation (by methods of geometric control theory) of temperature, humidity and velocity of air masses (and, in particular, of O_2 flows) in case of random change of one or several of these values.

Taking into account the unpredictability of the moment of change in the direction of rotation of the E. Lorenz carousel, this identification object is numerically irreducible [10].

This study shows how the application of fractal formalism and some relations of the molecular kinetic theory of gases to form a mathematical model of this object of identification partially eliminate the uncertainty resulting from the incompleteness of the formal axiomatic [10]. In the framework of fractal formalism for the formation of a model (air mass motion) with similar properties, we consider it necessary to establish the self-similarity regions of the determining parameter, and to prove the correctness of the statement "the moment of change in the direction of rotation of the E. Lorenz carousel is predictable", we apply the principle of external complement of S. Beer [11]. The application of such a new chosen description language acts here as a practical method aimed at partial elimination of the complexity arising from Gödel's incompleteness theorem [12 - 14]. It is to be expected that it is also the new language of description of the phenomenon that will not be able to bring an undecidable statement to an exact definition. This would require the application of an even higher level description language, and so on.

So, for this purpose, we will describe the self-similarity of the area of the determining parameter of the motion (more precisely, the circulation of air masses and, in particular, O_2) in a language of a higher level than the language that was applied before - in the language of fractal formalism. The study shows how the application of this language contributes to the determination of the moment of change in the rotation of the E. Lorenz carousel of air masses (which, incidentally, allows us to significantly reduce various energy inputs to maintain the functioning of forced ventilation in a closed sports facility/pool for artificial hypoxic training). For this purpose, we assume that the boundaries of the self-similarity region of the E. Lorenz carousel of the air masses of the facility are determined with an acceptable error by the constancy of the relations:

$$K = \frac{T_1 / V_1}{T_2 / V_2} \approx const, \tag{1}$$

where: $T_1, T_2 -$ represents the air mass temperatures in the two investigated areas (at the pool floor and at the pool ceiling, respectively); $V_1, V_2 -$ represents the velocity of air masses in these areas. Region V_1 **-** is the area in which the air mass velocity is determined at the minimum distance from the pool floor surface (area of the minimum value of the determining parameter); region $V_2 -$ is the area in which the air mass velocity is determined at a given distance from the pool floor surface (i.e. at the ceiling of an indoor sports facility for artificial hypoxic training) - the area of maximum value of the determining parameter.

The change in the direction of rotation of the air mass to the opposite direction does not occur instantaneously, but when the defining parameter approaches one of the boundaries of the self-similarity region, accompanied by a change in the sign of rotation. The time required to change the sign of rotation is the lag time, which can vary in a wide range from **0 до** ∞.

From the above, it follows that the E. Lorenz carousel of air masses in a closed-type sports facility (swimming pool) for artificial hypoxic training can be described by a fractal model, where the dimension of this model D is proportional to the value of the self-similarity coefficient:

$$D \sim K. \tag{2}$$

To keep constant of the partial pressure (its static and dynamic components) of the main components of the air mass (nitrogen, oxygen and water vapor), the relations and laws of the molecular-kinetic theory of gases are used in the work. Thus, for $i -$th air mass components **(**$i = \overline{(1,3)}$) (random) change in its characteristics (Δm_i - mass, $\Delta T -$ temperature, $\Delta V -$ velocity) should be controlled and regulated (until this parameter becomes comfortable for the athlete in the building) by special control sensors (temperature, humidity, velocity of air masses). In this case, based on the basics and principles of geometric control theory, the specified changes in the main characteristics of the building air masses and their reduction to comfortable (for athletes) values are as follows **(** ${m_i}^K$, T^K, V^K **)** should be determined and promptly eliminated using the following relationship:

$$\frac{\Delta m_i}{\left\{\dfrac{\mu_i \cdot \widetilde{V}}{R \cdot T^K}\right\}} + \frac{\Delta T}{\left\{\dfrac{\mu_i \cdot \widetilde{V}}{{m_i}^K \cdot R}\right\}} + \frac{\Delta V}{\left\{\dfrac{1}{\rho_i \cdot V^K}\right\}} = 0, \tag{3}$$

where: $\mu_i -$ mass of 1 kg-mole of $i-$ component, $R-$ universal gaseous constant, $\rho_i -$ compression of $i-$ component, $\widetilde{V} -$ the full internal volume of an indoor sports facility for artificial hypoxic training.

It should be noted that the geometrical image of relation (3) is a plane in the three-dimensional parameter variation space **(**$\Delta m_i, \Delta T, \Delta V$ **),** that passes through the point (0; 0; 0), with orthonormal vector with components:

$$\vec{n} = \left\{\frac{\mu_i \cdot \widetilde{V}}{R \cdot T^K};\ \frac{\mu_i \cdot \widetilde{V}}{{m_i}^K \cdot R};\ \frac{1}{\rho_i \cdot V^K}\right\}. \tag{4}$$

In swimming pools for sports swimming: 1) the air temperature is (25…29)^{0}C, that is

T^K= (298…302)^{0}K; 2) water temperature – (25…27)^{0}C; 3) relative humidity (denoted ${m_{H_2O}}^K$ **)** constitutes(50…60)%; 4) the velocity of air masses does not exceed 0,3 м/s (that is $V^K \le$ 0,3 м/s).

Table 1 shows the calculations of $\dfrac{\Delta m_i}{{m_i}^K}$, $\dfrac{\Delta T}{T^K}$, $\dfrac{\Delta V}{V^K}$ changes for $\widetilde{V} = 10^5\ m^3$.

Table 1. The calculations of $\frac{\Delta m_i}{m_i^K}$, $\frac{\Delta T}{T^K}$, $\frac{\Delta V}{V^K}$ changes for $\tilde{V} = 10^5\ m^3$

$\frac{\Delta m_i}{m_i^K}$	$\frac{\Delta T}{T^K}$	$\Delta V = 0$	$\frac{\Delta V}{V^K}$
+1%	-1%	0	-
+2%	-2%	0	-
+3%	-3%	0	-
+5%	-5%	0	-
0%	+1%	-	-2,6%
0%	+2%	-	-5,2%
0%	+3%	-	-7,8%
0%	+5%	-	-13%

Conclusions

1. The use of the E. Lorentz air carousel allows in this study to apply the methods of fractal formalism and modeling to describe the behavior of such numerically irreducible systems.

2. It should be noted that for such technologies of air mass circulation (without the use of forced ventilation) in indoor sports facilities for hypoxic training of athletes, the method of determining the self-similarity area given above can serve as an analog of an indicator that constantly registers the approach of the determining parameter to one of the boundaries of the self-similarity area, thereby signaling the probability of a situation that leads to a sharp change in the direction of air circulation.

3. The presence of such technology for regulating the movement of air masses in a sports facility can also significantly reduce energy costs for the functioning of forced ventilation system in it.

Conflicts of interest

The authors declare that they have no conflicts of interest with respect to the current study, including financial, personal, authorial, or any other that could influence the study and the results presented in this document.

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Data availability

All data are available in digital or graphical form in the main text of the article.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technology in the creation of the current work.

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Фрактальний формалізм у ідентифікації спортивних споруд закритого типу як систем з частковим індетермінізмом

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Анотація. В роботі розглянуті особливості функціонування і управління спортивними спорудами закритого типу, призначеними для здійснення штучного гіпоксичного тренувального процесу. Для ідентифікації подібних складних систем використовуються моделі різного типу в залежності від поставлених цілей. Складність вибору фізико-математичних моделей в даному випадку обумовлена складністю поведінки систем, що розглядаються, в різні моменти часу, на протязі якого можуть кардинально змінитись їх основні властивості. Використання повітряної каруселі Е. Лоренца дозволяє в даному випадку використати методи фрактального формалізму і моделювання для описування поведінки таких чисельно неприводимих систем. Наведено алгоритм визначення області самоподібності для досліджуваного об'єкту, що, в свою чергу, дозволяє понизити ймовірність порушення штатного режиму його роботи, конкретно: підтримання постійності статичної і динамічної складової парціального тиску кисню, необхідної вологості, швидкості і напрямку циркуляції потоку повітряних мас в даній споруді (без використання енергозахисної примусової вентиляційної системи). Розглянуті можливості використання фрактальних моделей і методів геометричної теорії управління для ідентифікації складних систем/спортивних споруд закритого типу, функціонуючих в енергозберігаючих режимах і призначених для проведення штучних гіпоксичних тренувань.

Зазначено, що для технологій циркуляції повітряних мас (що не використовують примусову вентиляцію) закритих приміщень , котрі призначені для гіпоксичних тренувань спортсменів, наведений вище метод визначення області самоподібності може слугувати аналогом індикатора, постійно реєструючого наближення визначального параметра до однієї з границь області самоподібності, й тим самим сигналізуючи про вірогідність виникнення ситуації, яка призведе до різкої зміни напрямку циркуляції повітряних мас у споруді.

Ключові слова: фрактальний формалізм, ідентифікація, спортивні споруди, системи з частковим детермінізмом, енергозберігаючі технології, методи геометричної теорії управління.