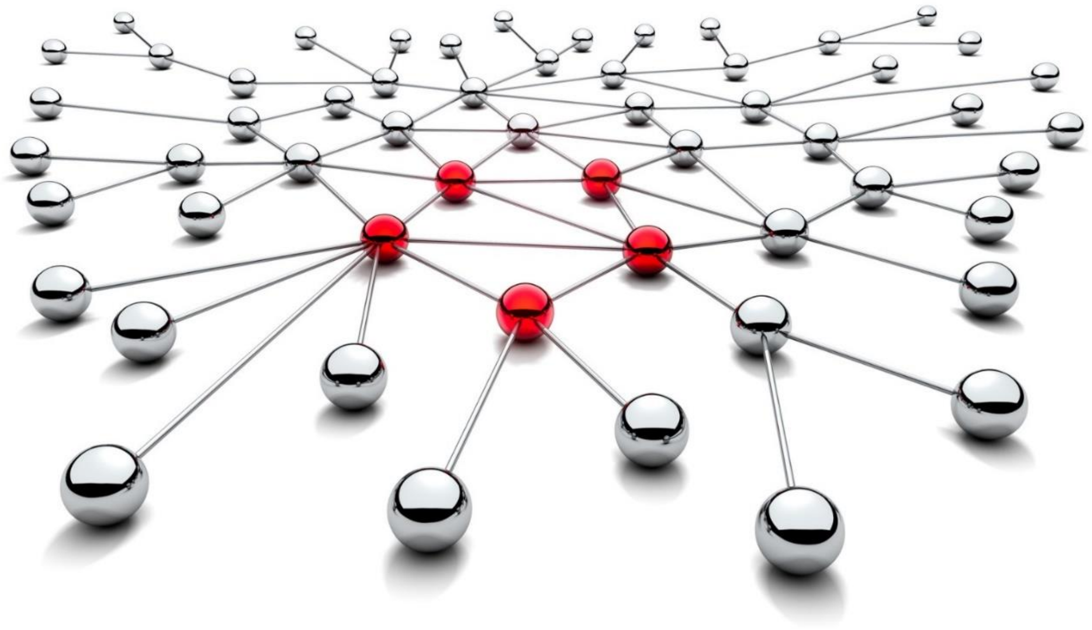

Air Ion Technology

in conditioning systems for data centers

Theoretical basis,
Products, Solutions,
Competitive Advantage
and Market Prospects

News bulletin 01/2018

OKBMAK MOSCOW MMXVIII

Practice should always be based upon a sound knowledge of theory

Leonardo da Vinci

The news bulletin was prepared by the specialists of OKB MAK, LLC on the results of research and development carried out by scientists and engineers of the organization in the period from 2012 to 2017. This document contains: comprehensive information justifying urgency of introducing an alternative technology for cooling IT equipment; theoretical and technical basis for building a new generation of air-conditioning systems for data centers, communications center, DCS, etc.; assessment of the general competitive advantages of Air Ion cooling systems for electronic equipment, general and specific sectoral recommendations for the most effective implementation of the proposed know-how.

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Contents

Introduction

The impulse to start work on the proposed subject was a commercial project, within which it was required to create a data center with the maximum level of mobility and autonomy. Preliminary analysis of available technical solutions has shown that while design techniques are developed in the part of providing mechanical strength of electronic complexes, and a wide range of solutions for constructing structures with the necessary strength characteristics are present in the market, there has been stagnation in recent years in the part of ensuring the temperature operating modes of IT equipment in the industry.

The modern data centers air conditioning market is a very complex and contradictory object. On the one hand, this is a "big business" with annual sales of more than US$ 2 billion and a growth rate of 11%. The world's electric power consumption by currently operated installations of this type exceeds 100 billion dollars a year. But on the other hand, refrigeration equipment, produced by numerous international and local vendors for many years, practically does not differ in its consumer properties, as it is designed according to unified "classical" norms. the developers of IT equipment have to work in the same rigid "thermodynamic" framework.

In order to find a way out of the described "crisis", special investment R & D was initiated in the OKB MAK. Theoretical and experimental studies have shown that the efficiency of air cooling systems for IT equipment can be increased manifold both in terms of productivity and economy.

1. State of the industry. The need for a new cooling technology

1.1 Classical electronic equipment air cooling technology. Pros and Cons

Air cooling systems for modern data centers occupy a dominant market position. This situation is explained by the fact that this technical solution has a unique set of design and operational advantages: versatility, scalability, simple technical realization and operation, etc.

However, the current generation of air cooling systems has inherent "irremovable" flaws, since all manufacturers of process conditioning systems for data centers develop their facilities based on a single thermodynamic model of heat transfer, in which the efficiency of removal of heat is limited by the permissible frequency of occurrence of electrostatic discharges , and the only mechanism to combat the formation of static charges of triboelectric nature is strongly normed humidification cooling air flow. This situation is postulated by both international standards (for example TIA-942), and domestic regulatory documents (RUSSIA: SN512-78). And although this technical solution has a long-term application history and is formally introduced into all industry regulations, this approach has significant drawbacks - limited effectiveness both in terms of equipment protection (even when the cooling air is moistened, about a quarter of failures of electronic devices are associated with electrostatic discharges, because the main protective component of this technology, an electrically conductive water film, is not formed on hot and hydrophobic surfaces), and in terms of energy efficiency. About 25% of the energy balance of any data center are consumed by refrigeration equipment for its own needs, in other words - "heats the sky". In addition, for some consumers of IT equipment, other "satellites" of humidified air, for example, electrochemical atmospheric and biological corrosion, can also cause tangible losses.

This state of affairs, of course, did not please industry experts. The last attempt to solve the problem was made in 2011, when the American Technical Committee ASHRAE 9.9 published the "Directive on the microclimate for the data center." This document introduced the classification of IT equipment and extended permissible ranges (in comparison with the standards of the TIA-942) for the temperature and humidity of the cooling air. However, this directive can hardly be considered as a solution to the problem, since the actual thermodynamic model for removing excess heat from electronic components has remained the same in this document, but for expanding the operating ranges of IT equipment and, as a consequence, reducing the costs of creating and operating of data centers conditioning systems users will be forced to pay with the increase in the frequency of failures of server and telecommunications equipment due to electrostatic discharges of triboelectrical nature.

1.2 Advantages of liquid cooling technology for data centers

Along with air cooling systems, IT equipment manufacturers also use alternative technical solutions. Among them, the most widely used technology is liquid cooling. Leaving aside consideration of the implementation options for this technology, it is possible to formulate the general advantages and disadvantages of such systems: high performance and energy efficiency (in comparison with air cooling); but (!) low manufacturability, high total cost of ownership, the limits of productivity growth and energy efficiency are limited by fundamental hydrodynamic factors (high viscosity, density, incompressibility, etc. of the heat carrier).

Nevertheless, at the moment liquid cooling systems are given certain priority when building high-performance computing systems, supercomputers or specific ("image"?) data centers.

2. Extended thermodynamic model of heat transfer in electronic devices

Before describing the new extended thermodynamic model of heat transfer, it makes sense to consider the classical standardized air cooling technology.

As mentioned above, the frequency of electrostatic discharges of triboelectric nature is adopted as a target function in solving the optimization problems in the mathematical model of heat transfer during air cooling of IT device components. The composition of the variables of this function can be divided into two groups - the characteristics of the cooling air flow: speed, temperature, relative humidity and the characteristics of the cooled device: the temperature and hydrophilicity of the active surfaces of the cooled elements.

The characteristics of the cooled surfaces are not standardized by unified international and national standards, but are determined by industry or corporate technical regulations. This specific information usually is not reported to the end user and is not considered as a tool for controlling the parameters of the cooling system.

As for the thermodynamic parameters of the cooling flow, they are strictly regulated and subject to precision control. In all normative documents, approximately the same values of the optimum temperature and humidity at the entrance to the cooled IT device are given: relative humidity RH = 50%; temperature T = 20 ° C. At the output from the device, this ratio of temperature and humidity is transformed as follows: RH = 20%; T = 37 ° C. The relative humidity in the "exhausted" air is key value in this cycle. The level of 20% is taken as a threshold, after which the frequency of electrostatic discharges of the triboelectric nature becomes unacceptably high. The speed of air flow with this combination of temperature and humidity should not exceed 300 m^3 / h per 1 KW of heat removed. Such a functional interdependence between relative humidity, temperature and speed determines the thermodynamic limit for increasing the specific productivity and energy efficiency of the data center conditioning systems.

To overcome this technological and thermodynamic deadlock, it was decided to abandon the indirect and limited effective method of controlling the formation of electrostatic charges of triboelectric nature (by humidifying air to a level above 20%) and proceed to the direct controlled deionization mechanism.

Within the framework of the new paradigm, the flow of cooling air in the innovative thermodynamic model is described by four INDEPENDENT parameters: speed, temperature, relative humidity and the level of primary ionization. By the level of primary ionization is meant the concentration of positive air ions (cations) in the air flow at the entrance to the cooled device. Primary ionization is formed due to natural ionization of air and artificial controlled emission of cations into the cooling stream. When an ionized gas passes through the zone of formation of an electrostatic charge, electromagnetic interaction occurs on the surface of the cooled element, the aeroion is attracted to the negatively charged surface, ions are recombined and a dangerous electrostatic charge is neutralized. Within the framework of the proposed Air Ion Technology cooling system for data center, such controlled emission of synthesized cations is called the direct controlled deionization mechanism.

It is obvious that the efficiency of the direct controlled deionization mechanism can reach 100%, since both the generation of electrostatic charges of the triboelectric nature, and the transfer of cations to the recombination zone occur synchronously with a single airflow. Because of the variety of design solutions used in the creation of IT equipment, the creation of a universal mathematical model of the deionization process is almost impossible. The required performance of the emitter of synthesized air ions for guaranteed compensation of electrostatic charges can be adequately determined only by experimental means. On special experimental models it is established that even in the limit conditions, the aeroion generator consumes no more than 0.5 W of electric power for 1 KW of extracted heat.

Further in the text, the term **IONOTRON** will be used to identify such special air ion generators.

3. Air Ion Technology for cooling IT equipment

3.1 Theoretical Basis of Air Ion Cooling Technology

As it was shown earlier, the thermodynamic model, underlying the Air Ion Technology, operates with four independent parameters: the temperature of the cooling airflow, the flow velocity, the relative humidity of the air and the concentration of air ions. Such independence gave occasion to a radical revision of the procedure for designating permissible operating modes for cooling IT equipment:

- Cooling flow rate is no more limited by triboelectric effects, but only mechanical strength of electronic equipment components (and in some special cases also acoustic limitations of the ergonomic property).
- Cooling air relative humidity is limited to upper bound only (dew point correlation for water film short circuit protection), lower bound restriction is lifted.
- The operating range for the cooling air temperature can be significantly expanded, the only objective basis for its setting is only the "thermal strength" of the element base of electronic equipment, all other limiting factors can be ignored.

3.2 Comparative analysis of the advantages of Air Ion Technology

3.2.1 Performance

The quantitative effect of the factors listed above on the cooling efficiency of IT equipment can be estimated using the known correlation for calculating the amount of heat removed:

$$Q = Vt\varrho c\Delta T,$$

V – cooling air flow; t – operating time of the refrigeration unit; ϱ – air density; C – air heat capacity ;

$\Delta T=(T2\text{-}T1)$ – the difference in air temperature at the outlet and in the entrance to the device.

Previously, it was shown that with a standard air cooling technology, one kilowatt of excess heat is removed from the device by a flow of air at a flow rate of 300 m³/h with a temperature drop of 17°C. In this case, the amount of heat removed is determined in this way:

$$Q_{ASHRAE}=300[m^3/h]t\varrho c(37\text{-}20)[\,°C]$$

Air Ion Technology allows to increase airflow three-fold and significantly expand the temperature drop at the inlet and outlet of the cooled device:

$$Q_{IONOTRON}=3*300t\varrho c(45\text{-}5)^{1}$$

Comparing the heat transfer equations for the classical and Air Ion Cooling Technologies, we can make an definite conclusion about the phenomenal potential that is inherent in the proposed innovation development:

$$Q_{IONOTRON}\ /\ Q_{ASHRAE} = 7,$$

i.e., introduction of Air Ion Cooling Technology allows to achieve a sevenfold increase in the performance of the cooling system of the data center.

Of course, with a change in temperature and humidity of air, its density and heat capacity change. However, within the framework of this document these processes will not be considered; the absolute variations of these parameters (density and specific heat) are insignificant, and the contribution of these fluctuations to the generalized mechanism of heat transfer is minimal.

[1] These values are experimentally confirmed, but not the maximum permissible values.

3.2.2 Power Efficiency

New extended thermodynamic model of radio-electronic equipment cooling, based on Air Ion Technology allows surpassing all existing data center technological conditioning solutions as regards power efficiency. In addition, the use of IONOTRONS in the systems of year-round Direct Freecooling minimizes restrictions on geographical (climatic) binding of similar data centers.

In support of this thesis you can compare Air Ion Technology-based solution with data center power efficiency market leaders:

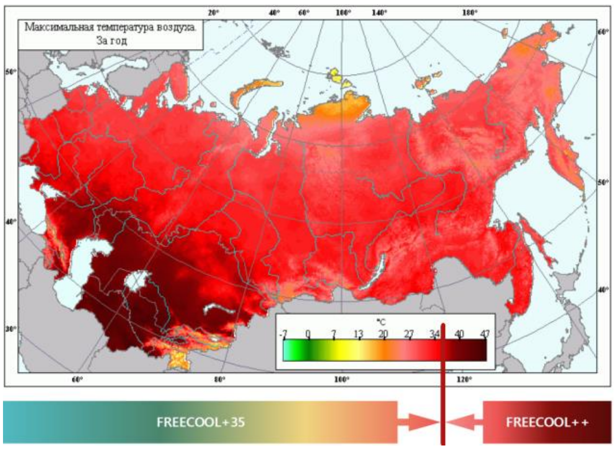
1. **facebook** Data center in Lulea, Sweden. Year-round direct free cooling with additional adiabatic distilled water cooling/moisturizing. Power Usage Effectiveness (PUE) = 1.04 (excluding water treatment cost).

2. **Microsoft** Data center in Dublin, Ireland. Year-round direct free cooling without additional adiabatic cooling/moisturizing. PUE = 1.17.

3. **IONOTRON-DC** - engineering infrastructure of Air Ion Cooling Technology data center. In the framework of the considered problem upper limit of operating-temperature range is of interest. During development of **IONOTRON-DC** engineering solution the logical choice was made: the "weakest" device operating temperature, i.e. +35°C to be base switching point

The presence of above mentioned temperature threshold caused the need for two **IONOTRON-DC** design solutions:

FREECOOL+35 - Data center conditioning system temperate climate version T ≤ Tmax = +35°C. Air flow rate 1 м³/s per 12 kW of waste heat (standard, without additional support).



FREECOOL++ - Data center conditioning system hot climate version T > Tmax = 35°C. Air flow rate 1 м³/s per 6 kW of waste heat (enhanced, with additional backup).

The whole territory of Russian Federation was adopted as climate zone for data center placement site. Calculation of engineering infrastructure power efficiency in extreme modes gives the following PUE values:

Figure 1. Maximum temperature of air in the territory of the Russian Federation, indicating the zones of applicability of the cooling system variants **IONOTRON-DC**

Calculation of engineering infrastructure power efficiency in extreme modes gives the following PUE values: (Power Usage Effectiveness): $PUE_{FREECOOL+35}$ = 1.03; $PUE_{FREECOOL++}$ ≤ 1.05.

Therefore for any region of Russia PUE annual average will be below 1.04.

On the basis of these estimates it looks very likely that Air Ion Technology implementation in data center cooling systems has favorable market prospects due to unique technological competitive product advantages combination and rising effective innovation-friendly data center market.

3.2.3 Reliability

There is practically impossible to develop a universal interindustry calculation algorithm of the new technology implementation economic effect, as it requires integration of a huge array of dissimilar facts. However, this problem can be formalized and correctly solved for any (type of) user. For example economic effect assessment of reducing accidents damage at fuel and energy complex production facilities is given below.

According to Rostekhnadzor and Ministry of the Russian Federation for Civil Defense, Emergencies and Elimination of Consequences of Natural Disasters fuel and energy complex production facilities suffer from approximately 175 major accidents annually with an average incident damage of $37m. DCS failure is one of accident causes.

Normally systems of this type comprise three elements: computer/controller + uninterruptible power supply + communication device. Theoretical calculation and statistics on GAZPROM production facilities give about the same probability value for such hardware complex full-year uptime: 0.37.

Using expert evaluation and GAZPROM group aggregated statistics allow to reckon the following:

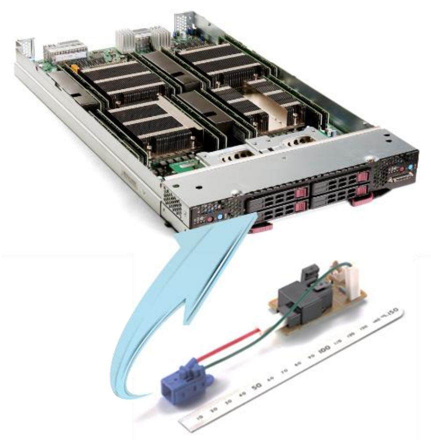
Total frequency of electronic equipment control complex accidents	0.633
Total frequency of electronic equipment control complex accidents, led to technological equipment shutdown	0.317
Frequency of electronic equipment control complex accidents caused by electrostatic discharge	0.158
Frequency of electronic equipment control complex "catastrophic" accidents caused by electrostatic discharge	0.00158
Annual loss per fuel and energy complex conditional technological unit caused by electronic equipment control complex electrostatic discharge	**$ 58,500**

Therefore expected annual economic effect of Air Ion Technology implementation will amount to **$50,000** per fuel and energy complex conditional technological unit due to reduced frequency of control electronic hardware complex failures.

3.2.4 Mobility

In terms of mobility and autonomy, data centers like **IONOTRON-DC** are the only and uncontestable leaders in the industry. The introduction of Air Ion Technology allows not only minimizing the power consumed by the engineering infrastructure, but also completely abandoning the onerous and costly forced humidification of the air (with the accompanying connection of the data center conditioning system to the water supply and sewerage systems).

3.3 Basic technical solutions for data center cooling systems



At the final stage of R & D, the specialists of OKB MAK analyzed all the main options for using air ion equipment while cooling electronic equipment complexes and prepared the following recommendations for optimal layout solutions. For those applications that use standalone single IT equipment (industrial applications, communications and the SOHO market), it is proposed to integrate the **IONOTRON**s directly into the housing of the electronic device (see Figure 2).

Fig. 2. Local cation emission. IONOTRON hardware implementation for server, storage or switch installation

For objects with "group" use of IT equipment, a modular IONOTRON was developed for installation in a server cabinet (see Figure 3).

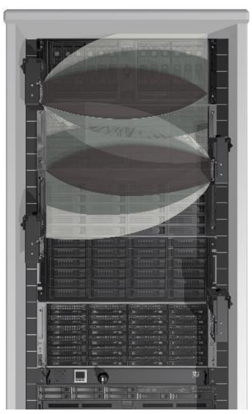
← Mounted bipolar emitter 0U

← Built-in bipolar emitter 2U

← Power supply unit

← Controller

Fig. 3. **IONOTRON** hardware implementation for server cabinet installation (local cation emission)



Air ion emitters are placed in the air intake area in such a way as to ensure guaranteed emission of cations into the cooling air flow for all consumers with the rack. Preliminary position of actuators can be determined on the basis of their ionization diagrams (see Figure 4). The presence of two types of emitters in the **IONOTRON** package for mounting in a cabinet is explained as follows: for server racks in industrial facilities it is important to provide mechanical strength of engineering systems. In this case, it is proposed to use the built-in 19-inch product with a height of 2U.

Fig. 4. Diagrams of ionization of mounted bipolar ionizers 0U

For other, for example, research purposes, a hanging emitter of aeroions of 0U type can be useful. It can be easily installed / dismounted on a 19-inch rack of the server cabinet outside the installation area of IT equipment.

After the completion of the rack installation on the running equipment, an instrumental control of the performance of the IONOTRON is carried out. For this purpose, a deionization control sensor is sequentially placed into the exhaust air outlet area of each device on the back side of the server cabinet (see Figure 5).

Similarly, this device is used to control deionisation in the server racks of the data center and in the layout solutions for large data centers, which are shown below in Fig. 6, 7 and 8.

Fig. 5. Sensor for controlling deionization efficiency in the controlled exhaust air sampling area

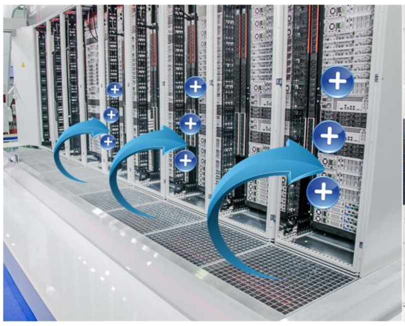


Fig. 6.
Zone cation emission.
Air ion emitter is integrated into elevated floor air diffuser

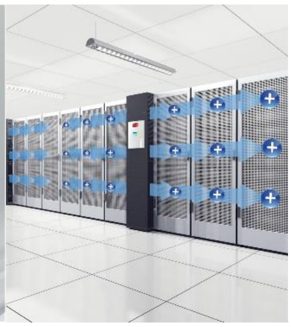


Fig. 7.
Zone cation emission.
IONOTRON is integrated into in-row air-conditioner

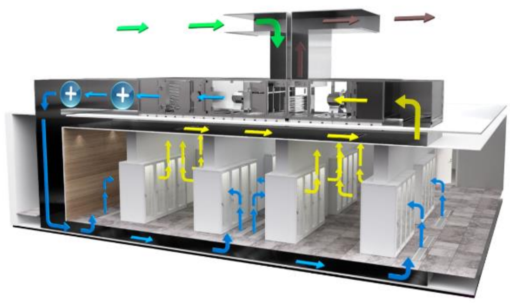


Fig. 8.
Total cation emission.
IONOTRON is integrated into air-handling unit. Technological conditioning system operates in Direct Free Cooling mode

Fig. 8 shows a process conditioning unit that operates in Direct Freecooling mode. This is the most power-efficient scheme in the industry for data center cooling systems.

Represented engineering solutions could be considered standard and all-purpose, for solving nonstandard engineering problems specialized IONOTRONs could be designed, having required dimensions, capacity and realizable ion balance.

3.4 Specific aspects of the implementation of Air Ion Technology

3.4.1 Manufacturers of IT equipment

The maximum effect of the implementation of Air Ion Technology by manufacturers of IT equipment can be obtained by bringing a new generation of "hot" servers to the market. As it was shown earlier, when the IT-equipment of IONOTRONs is used in the cooling system, the cooling flow rate can be multiply increased. For the same reason, the upper limit of the cooling air temperature at the inlet from the cooled devices can be increased. The coordinated, but functionally independent control of the temperature and speed of the cooling flow makes it possible to realize the required heat transfer efficiency within the servers. In the course of the experiments, it was confirmed that the energy-loaded components of IT equipment can be cooled by an air flow with a temperature of up to + 45 ° C without an increase in the failure rate due to overheating of electronic components.

The flow temperature at the entrance to the device, depending on the task to be solved, can be either increased (for the implementation of the year-round freecooling mode) and reduced (to stimulate heat transfer in energy-loaded servers and other similar devices). Preliminary calculations showed that based on Air Ion Technology it is possible to build an air cooling system that is superior in performance to solutions with a liquid coolant.

In addition to solving fundamental tasks to ensure the growth of productivity and power efficiency of cooling systems for IT equipment, the introduction of Air Ion Technology allows to solve a number of particular problems. For example, when designing their products, manufacturers of electronic equipment are forced to seek a balance between the hydrophobicity and hydrophilicity of the materials and coatings used, since the classical cooling technology with moistened air works only on hydrophilic surfaces, and vice versa, high hydrophobicity is required to protect against atmospheric and biological corrosion. For systems with ionized air cooling, this problem is completely removed, because hydrophilicity of the cooled surfaces is not required. Moreover, due to the organization of special bipolar ionization and ozonization of the air flow, it is possible to decrease radically the probability of occurrence of corrosion foci of a biological nature.

3.4.2 Manufacturers of air conditioning systems for data centers

To manufacturers of cooling systems for data centers, Air Ion Technology will enable to bring to the market products and solutions of previously unavailable energy efficiency. Of course, the maximum effect in this direction can be obtained only after the appearance on the market of a new generation of "hot" servers.

3.4.3 Owners and operators of data centers

For owners and operators of data centers, the integrated implementation of Air Ion Technology will significantly reduce the total cost of ownership both by minimizing the cost of building and operating its facilities, and by reducing by a quarter the failure rate of servers, storage systems and telecommunications equipment.

One of the positive moments that stimulate the penetration of Air Ion Technology into state-owned, corporate and commercial data-centers can be considered a wide and deep introduction of cloud IT technologies into our life. When building server factories for the operation of such services, the situation arises when the complex "monobrand" hardware solution becomes the best from the technical and economic point of view. That is, instead of maintaining the performance of inherited and inefficient platforms, the data-center operator can and should deploy a new, efficient and efficient IT infrastructure.

A by-side positive effect from the introduction of Air Ion Technology was discovered during the testing of **IONOTRON**s at real operating industrial facilities. By carrying out objective instrumental monitoring, the following fact was fixed: maintaining the concentration of air ions at the level of the upper limit of the sanitary standard for this parameter provides a significant reduction of static charges not only on the equipment and elements of the interior, but also on the human body. In relation to the human operator, **IONOTRON** performs the role of an effective virtual antistatic grounding bracelet.

3.5 Competitive advantages and prospects of implementation

3.5.1 DC Electronic Equipment Reliability

The transition from indirect methods (air moisturizing etc.) to physical processes of direct control of electrostatic charges formation and accumulation allows to achieve 100% triboelectric discharge protection of radio-electronic equipment.

Recommended for implementation at facilities:

- State-owned and corporate data centers with high availability requirements;
- Hardware DCS of nuclear power plants, fuel and energy complex etc.;
- Hardware military purpose automation system.

3.5.2 Power Efficiency

The use of controlled forced air ionization instead of air moisturizing allows to change electronic equipment air cooling modes fundamentally (to implement year-round direct free cooling and other power efficient processes).

Recommended for implementation at facilities:

- Data centers, hardware DCS and communications centers with independent or limited power sources;
- Power efficient Direct Free Cooling data centers;
- Prospective energy-loaded super servers, basic level supercomputers.

3.5.3 Mobility, Independence

Air moisturizing abandonment removes requirements for equipment room air conditioners connecting to water supply and sewerage systems. Air Ion Cooling Technology implementation provides highest level of mobility and independence for electronic equipment complexes such as data or remote communication center.

Recommended for implementation at facilities:

- Mobile special-purpose self-contained data centers, hardware automatic control systems and communications centers;
- Stand-by and disaster-proof data centers, hardware automatic control systems and communications centers.

3.6 Intellectual property protection


РОССИЙСКАЯ ФЕДЕРАЦИЯ

ПАТЕНТ

НА ИЗОБРЕТЕНИЕ

№ 2498427

СПОСОБ ОХЛАЖДЕНИЯ ЭЛЕКТРОННОГО ОБОРУДОВАНИЯ И СИСТЕМА ДЛЯ ЕГО ОСУЩЕСТВЛЕНИЯ

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Б.П. Симонов

The Air Ion Cooling Technology described in this document is the subject of intellectual property protection. All major technical and technological solutions are protected. Russian Federation Patent 2498427 (priority 05/16/2012) “Electronic equipment cooling method and system for its implementation”.

In addition, equipment manufactured in the R & D framework was tested by an independent testing laboratory and received an official conclusion on compliance with the specifications "Safety of low-voltage equipment" and "Electromagnetic Compatibility of Technical Means."

Conclusion

The presented materials contain the description of the fundamentals of Air Ion Cooling technology of data centers, basic technical solutions and recommendations for the effective implementation of this development. The staff of the **OKB MAK** invites the interested organizations to cooperate both in the part of implementing in the IT industry ready-made developments, and in solving new scientific and engineering tasks to develop this innovative sector of applied thermodynamics.

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