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Efficiency Evaluation Method for the Devices with Infrasound Impact on Functioning of Computer Equipment

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***Abstract*—A significant threat to critical infrastructure of computer systems has a destructive impact caused by infrasound waves. It is shown that the known infrasound generations are based on using the following devices: a Helmholtz Resonator, Generation by using a Pulsating Sphere such as Monopolies, Rotor-type Radiator, Resonating Cylinder, VLF Speaker, Method of Paired Ultrasound Radiator, and airscrew. Research of these devices was made in this paper by revealing their characteristics, main advantages and disadvantages. A directional pattern of infrasound radiation and a graph of dependence of infrasound radiation from the consumed power was constructed. Also, during the analysis of these devices, there was proven a set of basic parameters, the values of which make it possible to characterize their structural and operational characteristics. Then approximate values of the proposed parameters of each those considered devices, were calculated. A new method was developed for evaluating the effectiveness of infrasound generation devices based on the definition of the integral efficiency index, which is calculated using the designed parameters. An example of practical application of the derived method, was shown. The use of the method makes it possible, taking into account the conditions and requirements of the infrasound generation devices construction, to choose from them the most efficient one.**

***Keywords*—information security, computer hardware protection, infrasound, infrasound damage, efficiency evaluation method**

I. INTRODUCTION

ONE of the most important component of the modern information warfare is the possibility of a destructive impact on the critical infrastructure [2, 10] of a potential enemy, which is a set of hardware-software means for the operation of information systems, failure of which may result in substantial or irreversible negative consequences for the economy, well-being and health of the population, and for a stable flow of the political processes. Study results [23] indicate that the hardware most susceptible to damage by a destructive impact on the internal data storage of a permanent type are hard disk drives (HDD).

The basis of an HDD is a bloc of magnetic disks (BMD), rotating on a spindle and the read heads (RH), which are located close to the BMD. Accordingly, the main causes of HDD vulnerability is the presence of moving parts that are sensitive to vibrations, as well as the BMD sensitivity to electromagnetic impact. This also explains why there are two main types of destructive physical impact on the HDD: electromagnetic and vibratory.

The first type of impact leads to the magnetic disk demagnetisation and physical damage of information, that in some cases restorable by specialised software-hardware means [15]. The second type results in BMD and RH damage, which also leads to the loss of information, this time almost impossible to restore because the magnetic layer of BMD is significantly damaged. It should be noted that the destructive impact of the first type can be levelled by using the common means of protection of the G12B17/02 type (passive screen with grounding) (5) and a fractal-electromagnetic restructuris-er screen (a system of resistance to electromagnetic fields) [12].

At the same time, passive protection against vibration impact is studied a little, and active resistance to such influence causes inaccessibility of the protected information and, as a consequence, to the loss of the full functioning of a computer system. In addition, a relatively high sensitivity to vibration impact may characterize such hardware components as power supplies, multi-layer motherboards and computer cooling systems.

The mechanism of the impact of the second type is carried out during the occurrence of a resonance of the above elements of the computer systems. Due to the high sensitivity to vibrations, the result of such an impact is the physical disabling of the computer system hardware. It should be noted that according to [4, 17] the most dangerous vibrations are beyond the range close to infra-sound. The risks of such vibrations are confirmed by experimental research. These experiments revealed that as a consequence of the influence of the sound vibrations in the range of 15-30 Hz with a volume of about 80 dB, the BMD efficiency decreased by approximately 10 times.

The efficiency was evaluated by changes in the speed of the uniform data backup. Herewith, the radiator was located at a distance of several meters from the BMD of a personal computer. At the volume of about 100 dB the BMD completely failed due to contact with the case. The mechanism of the

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destructive impact of infrasound vibrations on the BMD is shown in Fig. 1.

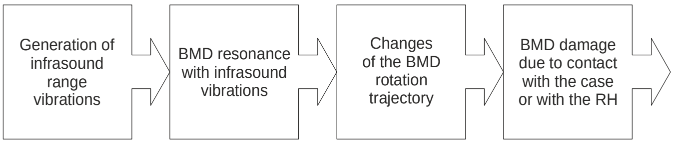

Fig. 1. The mechanism of the destructive impact of infrasound vibrations on BMD.

The infrasound vibrations radiator used in this experiment was compiled from publicly available components; it has a small size and low power consumption (800 W). This suggests that these radiators can be widely used for the provision of destructive impacts on the computer equipment of critical infrastructure. Their danger increases by the relatively small damping of infrasound vibrations passing through the air in an open space or passing through the walls of buildings. However, the results [4, 17] point to the absence of protection from vibro-acoustic waves of infrasound range in most common computer systems.

Therefore, the need to create widely available means of protecting the critical infrastructure of computer systems from destructive infrasound impact makes research in this area relevant. It is obvious that the creation of such protection is impossible without full-scale experiments. To do this, we need to create the appropriate experimental installation, based on the infrasound vibration radiator. It should be noted that the work is focused on the methods and means of protection especially of computer hardware. Thus, the vibration damage devices of relatively low power will not be considered here, their impact having no appreciable effect on the critical infra-structure. According to [24], such infrasound vibration is similar to the effect of the infrasound of 120 dB.

II. Analysis of the Existing Research and the Problem Statement

The critical infrastructure of any country is a big complex system of a strategic scale, which is a unity of a large number of elements of different types, joined by bonds of different kinds and having a common property (purpose, function) that is different from the properties of individual elements of the totality [7, 9]. The use of vibration means of impact on critical objects includes providing low-frequency impact on them. The transmission environment of such an impact may be the ground or the air. When using the soil as a transmission envi-ronment for vibration, the effectiveness of this impact implies high power losses and a low efficiency indicator due to the use of antivibration tools in computer systems. Accordingly, the most dangerous transmission environment of vibration is the air. It determines the danger of the infrasound impact as the infrasound frequency is ultra-low and equal to the vibration. In addition, this type of impact is virtually invisible to the critical infra-structure staff [24].

On analysing the works [1, 4, 11, 14, 17, 20, 22], it can be concluded that the approaches to the creation of the means of infrasound impact are less known, or based on any one method of generation. Also, this research does not include the classification of impact means, either according to the type of infrasound generation, or to the signal transmission environment. In addition, in the majority of the works analysed there are no preconditions for the development of an integrated approach for solving the problem of infrasound generation. Their absence is important because the authors describe some ways of impact generation with different values of the initial parameters for each of these methods, and without classifying them. Also, in the available literature the methods and means of generating vibration impact are described schematically, and complex evaluation of their effectiveness is missing. Considering this, the aim of this study is to develop a method for evaluating the effectiveness of the generation devices of infrasound impact on the functioning of the critical infrastructure of computer equipment.

III. The Main Part of the Research

By analogy with [10], at the first stage of the method development it is necessary to form a number of basic parameters by which it is possible to evaluate the structural and operational characteristics of infrasound radiation methods. It should be noted that in the available and reliable literature sources there is some information about infrasound generators. Thus, the authors considered the classic ways of infrasound generation, based on the use of the following devices: Helmholtz resonator, pulsating sphere such as Monopoly, rotor-type radiator, resonating cylinder, VLF speaker, paired ultrasound radiator, or airscrew.

A. Helmholtz resonator (HR)

The aim of the approach: generation of an elastic wave as a result of hollow device resonance of a specific form. Description of the approach. The Helmholtz resonator is an acoustic device of a spherical shape, a container with an open nozzle (see Fig. 2.), and in some cases a tube (see Fig. 3).

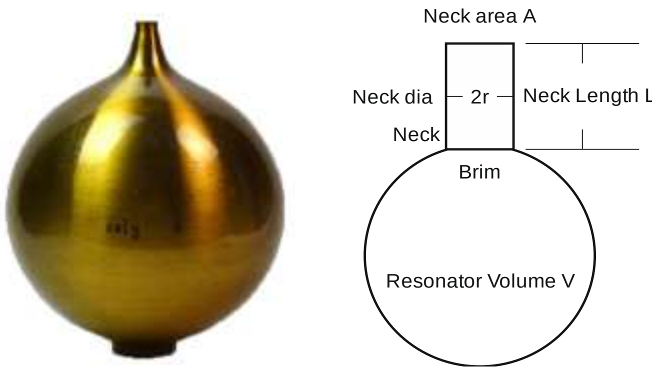

Fig. 2. Spherical Helmholtz resonator [8].

Fig. 3. Tubular Helmholtz resonator [26].

The resonator can perform low-frequency and ultra-low vibrations, the wavelength of which is much larger than the dimensions of the resonator [6]. An important aspect of infrasound generators is the resonance frequency. In the ultra-low generators the resonance frequency is the frequency displaying an abrupt increase of the vibration amplitude as a result of the coincidence of the generation frequency with the vibration frequency of the generator case.

The resonator frequency is calculated by the formula:

$$f_H = \frac{C}{2\pi}\sqrt{\frac{S}{V_0 L}} \qquad (1)$$

where f_H – frequency, Hz; C – speed of a sound in air (≈340 m/s); S – hole square, m^2; L – hole length, m; V_0 – resonator capacity, m^3.

The resonator responds exactly to the fixed-frequency sound, to the definite or blurred frequency range in the resonance area. As can be seen from the above formula, the resonance frequency is determined by the volume of the resonator and the nozzle size. It should also be noted, that a too long or narrow nozzle suppresses vibrations of the resonator [13]. An HR with high blurring of the frequency resonance area is often used as an artificial "infra-ear" to fix the presence of infrasound range vibrations.

Advantages of the use: This type of generation has a high coefficient of efficiency (COE) of the resonance (Fig. 6) and a relatively simple structure. Also, the HR is the most compact generator existing. The high availability of HRs is caused by their simplicity of design and the lack of moving parts. Their benefits also include the high directivity of the signal (Fig. 5).

Disadvantages of the use: The main disadvantage is that each individual HR has its own unique resonance frequency with minimal blurring of the amplitude frequency response (AFR) and this frequency cannot be changed after manufacture of the HR without significant design changes. Also, a disadvantage is that the HR size is inversely proportional to the size of the resonance frequency. An HR is used as amplifier of vibrations and cannot fully generate them. Resonance occurs only under external influence on the HR at certain frequencies corresponding to the resonance frequency of a particular example.

B. *Generation by using a pulsating sphere such as Monopoly (GPS)*

The aim of the approach: Generation of infrasound vi-brations occurs due to compression and stretching of an elastic sphere.

Description of the approach: The pulsating device is typically a rubber sphere with a diameter of about 1 m, connected to a reservoir of the compressor, which compresses the air up to three or more atmospheres. The connection is made through a tube with a tap, which is rotated by the desired number of rotations and periodically connects the sphere to the compressor and then disables it.

The tap rotation is made by means of a DC motor. The sphere pulsates with an amplitude of 5 mm at 15 Hz, and is a source of infrasound.

Advantages of the use: The use of the GPS system makes it quite easy to change the generation frequency by changing the rotational speed of the electric motor and the pulsation amplitude by changing the pressure in the compressor tank.

Disadvantages of the approach: a low efficiency was experimentally proved in generators of this type. This is due to the dependence of the radiation intensity on the squared ratio of the radiation size to the wavelength. For infra-sounds this ratio is small, and thus the intensity of the radiation is negligible. One should also note the difficulty of manufacturing, the lack of focus of the sound wave (Fig. 5) and the low lifetime of the GPS.

C. *Rotor-type radiator (RR)*

The aim of the approach: Infrasound wave is generated by the sphere's eccentric vibrations, placed on the rotor of the motor (Fig. 4).

Description of the approach: The RR consists of an elastic rubber sphere with a diameter of 30 sm. The sphere is tightened into the net and is attached to the metal bracket located at the hole of the steel disc, placed on a motor axis. The disk rotates in a horizontal position. The motor is asynchronous with the rotation frequency at 15 to 20 turns per second. The net mounts can be positioned at any distance from the axis of rotation, thus changing the rotor sweep.

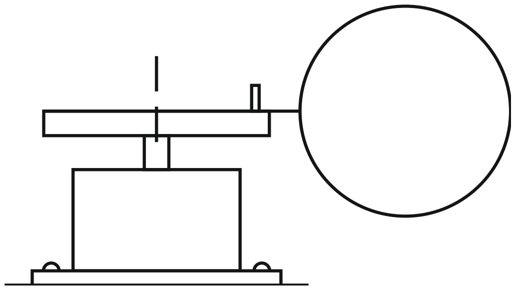

Fig. 4. Construction of the rotor-type radiator.

The rotating RR generates a moving circular wave, which causes periodic compression and rarefaction of air around the device, and generates infrasound.

Advantages of the approach: Structurally, the RR is one of the best options for infrasound generation due to its ease of development, high efficiency (Fig. 6) and long operating time.

Disadvantages of the approach: The disadvantages of the RR include the lack of a radiation pattern (Fig. 5) and the need of hard mounting of the structure on the surface.

D. *Resonating cylinder (RC)*

The aim of the approach: The method consists of the resonance of a metal (usually copper) cylinder by passing inside its pulsating air mass.

Description of the approach: VLF vibrations generation is carried out by air passing through the internal volume of the cylinder. There are two variants of this method for infrasound signal generation: labial and ten-on. In the first case, the air is placed into the cylinder by the individual pulses. This is done by opening and closing the air valve at a certain frequency. For this purpose, the valve (or tap) connects to the motor that rotates at a certain speed. Motor rotation speed (turns per second) determines the opening/closing rate of the valve and vibration frequency. Generation of the second type (ten-on) is made by setting the metal plate at the foundation of the cylinder of a certain size. When air passes through the internal volume of the cylinder, the plate creates elastic vibrations. The size of this plate and the air velocity through the cylinder determine the frequency of signal generation. The cylinder itself carries out the function of the resonator (vibration amplifier). The size of the cylinder is calculated by the formula:

$$L = \frac{S}{f} \tag{2}$$

where L – the length of the cylinder, m; S – sound speed, m/s; f – resonance frequency, Hz.

Advantages of the approach: The main advantage of the RC is a high directionality of the sound waves. Using the RC with a resonant frequency of 18-20 Hz, at a distance of 50 m, the focal point does not exceed 15 m in diameter. Also, this approach of the generation of low-frequency signals is one of the most effective ones. A value of watts on decibel is in the range of 1 to 90 dB; 1 decibel is less than 15 watts.

Disadvantages of the approach: The disadvantages of the use of the RC include the large size of the installation. The resonator designed for the frequency of 18 Hz will have a length about 19 m. Using the double generation and generation at the second vibration can reduce the size of such installation twice, but with these modifications the RC is the largest one of the considered variants.

E. VLF speaker

The aim of the approach: An infrasound wave is generated by the diffuser vibrations on an elastic hanger and on the device case resonance.

Description of the approach: The diffuser is fixed on an elastic hanger. On the inner side of the diffuser there is one of the windings of the inductor reel. The second reel winding and permanent (more rare earth) magnet are placed around the first loop of the inductor reel. The first reel loop receives a sinusoidal (sometimes rectangular) signal which generates a magnetic field between the reel windings. Due to this, after the growth of the second signal the second reel winding push the first one, and together with it is pushed into the diffuser. With signal recession, the force acting on the first reel is reduced and the elastic hanger returns the diffuser (and together with it the first reel winding) to its original place.

An important aspect of using the VLF speaker is the calculation and production of the device case, the resonant frequency of which will correspond to the radiator. The resonant frequency of the case VLF speaker is calculated according to the formula:

$$F = \frac{C}{2\pi}\sqrt{\frac{S}{LV}} \tag{3}$$

where F – resonant frequency; C – sound speed in air (≈ 340 m/s); π – number=3.14… ; S – hole square of the phase inverter; L – effective length of the phase inverter (length of the phase inverter plus 5%); V – case size.

Advantages of the approach: The proposed approach to the generation of infrasound range signal is the most affordable. Almost all the components for creation of the VLF generators are in free sale. Also, there is a lot of technical literature on the development of VLF speaker.

Disadvantages of the approach: One of the constructive features is the complexity of developing and setting the device case, the parameters of which have a significant impact on the device's resonance frequency. Changes of the resonant frequency settings entail significant changes in case construction. This is why the dynamic change of generation frequency with the maximum efficiency is impossible. Also, the use of the VLF is not effective due to the fact that the power consumed for the generation increases exponentially together with the increasing volume.

F. The method of paired ultrasound radiators (MPUR)

The aim of the approach: The method of paired ultra-sound radiators involves the use of several (usually two) ultrasound radiators to generate ultrasound waves at the focal point of both radiators.

Description of the approach: The MPUR method uses the principle of nonlinear overlay of ultrasound beams. With the help of ultrasound radiators (usually, piezoelectric elements) high-frequency signals of high directivity are generated. The focal point of these signals, due to nonlinear frequency shift, occurs in an infrasound impact zone.

Advantages of the approach: the MPUR method is one of the most energy-efficient methods, because it uses indirect infrasound generation by ultrasound signal overlay. The advantages also include the fact that the infrasound impact zone is limited by the focal point of the infrasound signals, and consequently the infrasound impact will not affect the radiator lines in the close proximity to them. This makes it relatively safe to conduct research without the need to consider the harmful effects on the environment. Also, the negative impact will not extend to the actual installation and the maintenance staff.

Disadvantages of the approach: The MPUR system is a component, and consequently the failure or loss of the focus on one of the components will stop the effective functioning of the system. Also, to achieve a volume of more than 100 dB, it is necessary to use high-energy installations, which are not freely available.

G. Airscrew (AS)

The aim of the approach: Infrasound is generated by the ability of wind installation blades to resonate at a certain frequency.

Description of the approach: At the operation of two-bladed and three-bladed wind installations of the horizontal axis type, except the noise in the audible range, at a certain rotation frequency and in the infrasound range, there is a strong vibration. The volume of such a vibration often reaches 90-110 dB [18]. The same feature is inherent to vertical axis rotors of Darrieus and Savonius [25]. In [19] it is shown that the nature of this infrasound is associated with the effect of the "whirling" sound or "aeolian tones". The spectrum of such sound consists of weak background (whirling sound) and of one sharp peak of high intensity. Based on the research results [3] it was determined that the basic tone of AS infrasound frequency can be calculated using the Strouhal formula:

$$f = \frac{St \times v}{R_0} \tag{4}$$

where St – Strouhal number; R_0 – blade length; v – flow speed, which wraps around the blade.

The directivity features of the infrasonic harmonics of the AS-type generator's acoustic field are shown in Fig. 5.

Advantages of the approach: Advantages of the AS-type generator are associated with its relatively large dimensions. This makes it possible to achieve high area coverage. Beside this, it is possible directly to affect the objects that are not at very high obstacles.

Disadvantages of the approach: The main disadvantage of the AS is its large size, heavy weight and low efficiency coefficient. In order to generate infrasound waves using the AS we must not only rotate the screw at an appropriate frequency, but also use a screw whose size corresponds to the set resonance frequency. Using the infrasound range, the screw size is sufficiently large (due to the large wavelength). Also, a significant disadvantage of the AS generator is the wide directivity of the action (Fig. 5). The radiation is carried out not only directly on the device's orientation, but in the opposite direction, and partly to the sides.

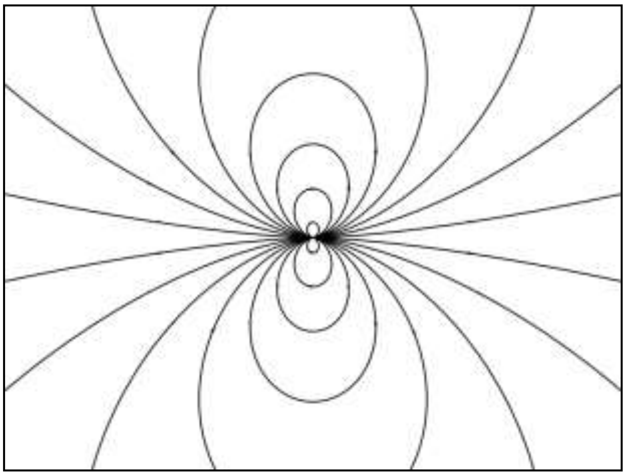

Fig. 5. Directivity features of the infrasound harmonics of the AS-type generator's acoustic field.

IV. Analysis of the Infrasound Sources

As a result of analysis of sources [6, 12, 13], based on the methods and devices already discussed, directivity patterns were constructed (Fig. 6). The graph of dependence of infrasound radiation volume from the consumed power is shown in Fig. 7.

In addition, the research has made it possible to propose a number of basic parameters by which we can evaluate the effectiveness of infrasound radiation:

1. Minimum frequency – minimum frequency at which the coefficient of efficiency of the device is at least 30% from the coefficient of efficiency at the resonance frequency (Hz).
2. Maximum frequency – maximum frequency at which the coefficient of efficiency of the device is not less than 30% from the coefficient of efficiency at the resonance frequency (Hz).
3. Minimum volume – lower working volume threshold (dB).
4. Maximum volume – the upper maximum volume threshold at a distance of 50 m from the device
5. (dB). As it is infrasonic radiators that are considered, which do not have a significantly destructive effect on biological objects, then, as was indicated above, the upper limit for this parameter is 120 dB.
6. Maximum capacity – maximum working power that can be achieved by using the components that are commercially available (W).
7. Weight return – approximate weight of the device, designed for a working volume of 120 decibels (kg).
8. Dimensional return – approximate size of the device (dimensions), calculated on the working volume of 120 dB (m^3).
9. Directivity – infrasound signal angle (rad).
10. Generation costs coefficient – the power expended on the generation of one decibel at a volume of 120 dB (W/dB).
11. Harmonics percentage in the signal – the maximum signal deviation from the standard (%).
12. Noise coefficient – volume noise ratio to the base signal volume (%).
13. The availability of accessories on sale – possibility to buy accessories, or to manufacture them without specialized equipment (0 or 1).

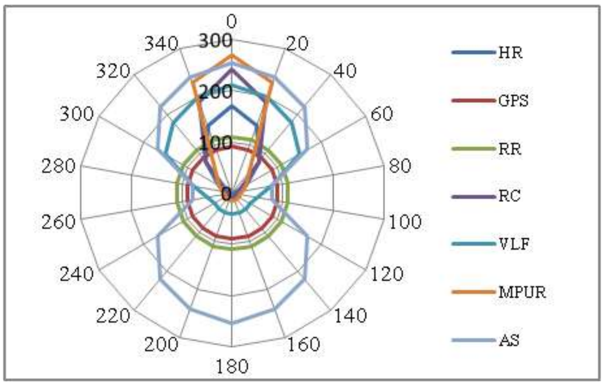

Fig. 6. Directivity pattern of the infrasound radiation.

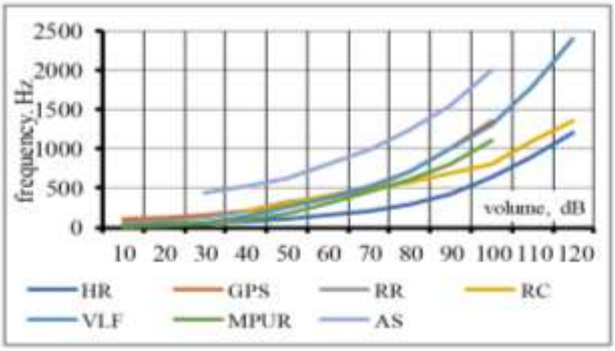

Fig. 7. A graph of dependence of the infrasound radiation volume on the consumed power.

The resulting list of basic parameters may be expanded as a result of further research. Approximate values of these parameters for the studied generation devices are presented in Table 1.

The formation of the list of basic parameters shown in Table 1 makes it possible to go to the second stage of the evaluation method development, which comprises the development of a mathematical apparatus for the calculation of the integral index of efficiency. Using the results of [16, 21], the following expression is used:

$$\nu_{\Sigma} = \sum_{i=1}^{I} \alpha_i \nu_i \qquad (5)$$

where ν_{Σ} – integral index of efficiency, α_i – weight coefficient of i base parameter, ν_i – value of i base parameter in a normalized form, I – number of base parameters.

It should be noted that determining the weight coefficient values α_i requires separate research. The significance of these parameters depends on the resources available to create infrasound radiator, and on the tasks that it must perform.

It should also be pointed out that the basic parameters shown in Table 1 have different units of measure. Furthermore, for different parameters the growth of their values has not only positive but also negative impact on efficiency. For example, an increase of the parameters x_1, x_3, x_6, x_7, x_8, x_{10}, x_{11} negatively affects the integrated indicator of efficiency.

At the same time an increase of the parameters x_2, x_4, x_5, x_9, x_{12} has a positive effect on the integral indicator of efficiency. Therefore, in order to use the values shown in Table I in expression (1), their normalization must be done. According to [21], it is possible to use the following expressions:

$$\nu_i = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}} \qquad (6)$$

$$\nu_i = \frac{x_{\max} - x_i}{x_{\max} - x_{\min}} \qquad (7)$$

where $x_{\max}$, $x_{\min}$ – maximum and minimum value of the parameter x_i.

TABLE I
APPROXIMATE VALUES OF THE INFRASOUND RADIATION EFFICIENCY EVALUATION PARAMETERS

Parameter	Parameter nomination, dimension	HR	GPS	RR	RC	VLF	MPUR	AS
Minimum frequency	x_1, Hz	1	3	5	12	4	1	11
Maximum frequency	x_2, Hz	90	25	40	30	100	45	28
Minimum volume	x_3, Db	1	1	1	35	1	1	32
Maximum volume	x_4, Db	120	100	80	120	120	100	120
Maximum capacity	x_5, W	3500	1350	590	2900	5000	1200	400 0
Weight return	x_6, kg	10	140	80	350	100	120	500
Dimensional return	x_7, m^3	0,096	1,6	0,144	2,88	1	1,008	28
Directivity	x_8, rad	60	360	360	35	85	40	280
Generation costs coefficient	x_9, W/Db	6,4	13	10	8	13	11	20
Harmonics percentage in the signal	x_{10}, %	11	15	26	9	14	6	28
Noise coefficient	x_{11}, %	5	31	42	17	14	7	39
Availability of accessories on sale	x_{12}	1	1	1	1	1	0	1

Equation (6) will be used for positively oriented parameters and the expression (7) – for negative oriented ones. From the standpoint of the problem, identifying the most effective infrasound radiation device is focused on the selection of devices for which the integral value ν_Σ will have the highest value:

$$If \max_{\nu_\Sigma(j)} = \{\nu_\Sigma(j)\}_J \tag{8}$$

where $\nu_\Sigma(j)$ – integral index of efficiency for the *j* device calculated with the help of expression (1), *J* – number of investigated radiators.

As a result, the following method of evaluating the effectiveness of infrasound radiation methods can be proposed:

Step 1: The problem analysis to determine the list of available methods of infrasound radiation.

Step 2: In-depth analysis for the available met-hods of radiation to specify parameter values shown in Table. 1.

Step 3: Using expressions (6, 7) to carry out normalization of parameters defined in the previous step.

Step 4: The analysis of the problem conditions of the infrasound radiator to determine the values of weight coefficients.

Step 5: Using expression (5) to determine the value of the integral index of the effectiveness of each available devices.

Step 6: Using expression (6) to determine the most effective infrasonic radiation device.

Let us consider the proposed method of evaluating the effectiveness on a carefully selected example. Let us assume that it is possible to use all methods of radiation, which are listed in Table 1. Also suppose that the weight coefficients of all the parameters are the same and equal to 1. The task is to evaluate the efficiency of all available devices of infrasound radiation and determine the most effective of them. Note that the problem is conditional: because of the same weight coefficients it does not take into account either the creation conditions of infrasound radiation devices or the features of their use. In this case, evaluation of the effectiveness of different radiation devices begins with step 2 in which, in accordance with expressions (6) and (7), normalized parameters of effectiveness evaluation are calculated. For example, for the HR normalized minimum frequency, which is a negatively oriented parameter, in accordance with expression (7) it is calculated as:

$$v_1 = \frac{12-1}{12-1} = 1 \tag{9}$$

For the same HR normalized maximum frequency, which is a positively oriented parameter, in accordance with expression (6) it is calculated as:

$$v_2 = \frac{90-25}{100-25} = 0{,}87 \tag{10}$$

Normalized parameters calculated according equation (10) for all considered infrasound radiation devices are shown in Table II. In the same table, calculated for each of the above devices, the values of the integral index of efficiency are shown.

The largest integrated indicator of efficiency has the HR, and because of it, from the standpoint of the problem, this device is the most effective.

TABLE II

APPROXIMATE VALUES OF NORMALISED PARAMETERS OF EVALUATION THE EFFECTIVENESS OF INFRASOUND RADIATION DEVICES

Normalised parameter	HR	GPS	RR	RC	VLF	MPUR	AS
v_1	1,00	0,82	0,64	0,00	0,73	1,00	0,09
v_2	0,87	0,00	0,20	0,07	1,00	0,27	0,04
v_3	1,00	1,00	1,00	0,00	1,00	1,00	0,09
v_4	1,00	0,50	0,00	1,00	1,00	0,50	1,00
v_5	0,85	0,22	0,00	0,68	1,29	0,18	1,00
v_6	1,00	0,73	0,86	0,31	0,82	0,78	0,00
v_7	1,00	0,95	1,00	0,90	0,97	0,97	0,00
v_8	0,92	0,00	0,00	1,00	0,85	0,98	0,25
v_9	1,00	0,51	0,74	0,88	0,51	0,66	0,00
v_{10}	0,77	0,59	0,09	0,86	0,64	1,00	0,00
v_{11}	1,00	0,30	0,00	0,68	0,76	0,95	0,08
v_{12}	1,00	1,00	1,00	0,00	1,00	0,00	1,00
v_Σ	11,42	6,62	5,52	6,37	10,56	8,28	3,55

V. CONCLUSIONS

It was determined that a significant threat to the critical infrastructure of computer systems has a destructive impact caused by infrasound waves. It is also deter-mined that most of the means of infrasound generation are based on using the following devices: Helmholtz resonator, pulsating sphere, rotor-type radiator, resonating cylinder, VLF speaker, paired ultrasound radiator, and airscrew.

The research of these devices revealed their characteristic features, advantages and disadvantages. The directivity pattern of infrasound radiation and a graph of dependence of the infrasound radiation volume on the consumed power were created.

Also, because of analysis of these devices, a number of basic parameters were selected, the values of which make possible to characterize their structural and operational characteristics. For each of the devices approximate values of the proposed parameters were calculated.

A new method was developed for evaluating the effectiveness of infrasound radiation devices based on the definition of the integral index of efficiency, which is calculated using the designed parameters. An example of the practical application of the developed method was shown.

This research indicates Helmholtz Resonator as having the largest indicator of efficiency, and become the most efficient device related to infrasound radiation.

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