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AN EXPERIMENTAL INVESTIGATION OF INFRASOUND INFLUENCE HARD DRIVES OF A COMPUTER SYSTEM

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ABSTRACT

The relevance to investigate the influence of low-frequency sound oscillations on universal computer system hardware is shown. Based on the analysis of hardware functionality and protection modern technologies, it is determined that hard disk is the most vulnerable part of the computer system. An experimental setup has been developed, which makes it possible to investigate the functional state of hard disk at various parameters of infrasonic and close to its effects. The changes in data writing/reading speed was studied depending on the frequency of infrasonic radiation and the waveform. The influence power was 60 dB, 80 dB, 110 dB and 140 dB. The frequency range varied from 5 Hz to 32 Hz. The influence of such waveforms as a sinusoid, meander, triangle, sawtooth, reverse sawtooth is investigated. It is determined that the most dangerous is a signal with a frequency about 27 Hz and the sinusoidal and meander waveforms. It is also determined that at a power influence 140 dB, the hard disk completely failed due to touching the reading heads of its surface. It was suggested that the destructive low-frequency sound effect can be leveled by using inertial protection elements, which predetermines the ways of further researches.

Key words: information security, computer equipment protection, vibration, vibration damage, infrasound, infrasound influence.

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1. INTRODUCTION

Data from literature sources [1-3] and the results of own research [4-6] indicate that vibration exposure is one of the most effective methods of damaging computer systems, while hard disks (HDD) demonstrate the widest sensitivity to this effect. The main danger for HDD is the high amplitude of oscillations between the block of reading heads and the block of disks, because the latter have a low inertia through the gyroscopic effect due to their rotation at high speed. Since the distance between the reading head block and the magnetic disk unit (MDU) is 0.05 μm [2], which is even less than the displacement of the disk block relative to the housing, then the read head actuator will lead to a contact between the MDU surface and the reading head slider, i.e., this causes their mechanical damage. Analyzing the declared characteristics of the hard disks, it was found out that the HDD of only server and business class (in the business class only mobile versions) are equipped with systems to protect and counteract concussions or bumps. In the characteristics presented in the public domain, there was no protection against the acoustic-vibrational effect of infrasounds in the range. This current research shows an experimentally investigation of acoustic-vibration influence on HDDs and the possibility of damaging HDD or data stored on it, as a result of such an influence.

Theoretical and experimental studies of noise and vibration, as well as their influence, have been carried out since the 1950s [5]. There are institutes that deal with the problems of studying vibration and noise and creating means to reduce their impact on people and environment. Analyzing similar studies on the example of developments of the Acoustics Institute named after N.N. Andreev, it can be concluded that a human acts as a recipient of noise or vibration. Consequently means and methods of counteraction are being developed precisely to protect human body from the negative effects of vibration and noise. As a rule domestic institutions do not deal with the problems of ultra-low-frequency acoustic and vibration effects on computer equipment. It was possible to find open-source studies of several components of the aerospace sphere that are most sensitive to the vibrational effect, among which there is no research of hard disks.

Siemens Corporation [1] defined the different sensitivity levels of hard disk drives in the sound spectrum from 353 Hz to 10kHz. Nickerson, et al [6], compared the performance degradation of hard drives when exposed to tones, broad noise with tones, and broadband signals. In the test function generator was used to produce sinusoidal noise from 1 kHz to 16 kHz.

At the same time, there are no open-source research related to the impact of infrasound on PC. Each of the manufacturers of A-brand hard disks makes HDD testing for resistance to vibrations or bumps. The testing is carried out in accordance with the HDD destination and hardware and software protection, which are available in the HDD model being tested. For example, a series of WD Reds designed for research in server solutions and NAS-drives is tested for the ability to withstand resonant vibrations arising in server racks or NAS systems with a large number of hard disks and has a built-in 3D Active Balance Plus system to compensate the destructive impact of parasitic vibrations in multi-disk NAS systems, RAID arrays and other devices using a large number of HDD. Business class models such as WD

Black Mobile in a 2.5-inch form factor designed for premium mobile solutions (laptops, ultrabooks) are tested for the ability of sensors to fix hits and bumps and park readers during strong hits or vibrations, because they have built-in system to counteract the destructive impact of bumps.

Technologies for emergency parking of NoTouch head in hard disks of Western Digital Company, as claimed by the manufacturers, are effective for counteracting falls and not strong bumps. Nevertheless any information on the ability to resist vibration or protection against it could not be found.

Considering the above points, the aim of this study is to determine and analyze the consequences of acoustic-vibration influences on the hard disk and the computer system as a whole.

To achieve this goal, it is necessary to solve the following tasks: to make test measurements with different values of frequency, waveforms and sound pressure; development of evaluation criteria, evaluation of the destructiveness of acoustic-vibration influence in accordance with the criteria set.

2. TEST DESIGN

Analyzing the studies [4], to generate the acoustic-vibration influence the method of the ultralow-frequency column (ULFC) was chosen, because it is the most common and simple [7] in the implementation.

Figure 1 Functional scheme of oscillation-vibration influence generator

A classical [8] acoustic scheme was used (Fig. 1), where generator is the modified signal generator FG-100 DDS, amplifier - Hertz HP 1 KD ULF amplifier with a demodulated infrasound filter, emitter - composition of the Rockford Fosgate T2S213 emitter and the body, modified to shift the resonant frequency into the infrasonic range.

2.1. Description of the Test Stand

For testing model WD3200AAJS HDD of Western Digital (WD) company was selected. By February 11, 2017 this model is the most popular on the domestic market (among the HDDs with a capacity of less than 600 GB) and has an optimal (the lowest "cost" of 1 GB among the medium and high price range manufacturers of A-brands HDDs) price ratio. For this experiment HDD models no older than 2015 year's production were selected.

The test PC is built into a typical Mini Tower type body. The test PC includes a motherboard of mini ATX size, the fifth generation central processor Intel Core 2 Quad (2 generations older than the current) and DDR type 4 GB RAM.

All used components are new and checked for the presence of any defects, during which problems and errors were not found. The HDD is installed in the regular [9] place and fixed with fixing anchors, included in the basic package configuration. For the test, Windows 8.1 Enterprise was installed. The emitter and the test PC are installed on various surfaces at a distance of 3 meters to minimize the vibration influence through the surface and to reduce parasitic noise. The sound pressure was controlled using universal sound and vibration meter RST-00026, installed 10 cm from the test PC body towards the emitter.

2.2. Progress of the Experiment

The HDD that was used in the experiment was cleaned by double formatting with a complete reset of all clusters. As a result of multi-stage formatting, the graphics of the writing speed and reading of a homogeneous data array looked like a horizontal line. After the reset, the HDD was faulted using Victoria 4.46b, which showed a complete absence of sectors with a response time more than 50 ms.

To load HDD during the experiment, a copy operation was performed to a homogeneous data array between logical disks created on a single physical disk, which in fact was a step-by-step data reading and writing process. Two switch-ons were made (10 seconds each) and the smallest write-read speed was fixed. The average of the 2 iterations for each of the frequencies and waveforms was recorded in a table.

Table 1 Dependence of the recording speed of a homogeneous data array on the frequency of influence and the waveform at 60 dB

Frequency (Hz)	Waveform(Mb/sec)				
	sinusoidal	**meander**	**triangle**	**sawtooth**	**reverse sawtooth**
5	35, 2	35, 3	35, 6	35, 2	35, 7
8	35, 1	35, 3	35, 5	35, 4	35, 4
11	35, 3	35, 2	35, 3	35, 3	35, 4
14	34, 6	35, 1	35, 4	35, 1	35, 5
17	34, 2	34, 7	35, 1	34, 8	35, 2
20	33, 7	34, 4	35	34, 4	35, 1
23	33, 3	34, 5	34, 8	33, 9	34, 9
26	33, 6	34, 1	34, 7	33, 8	34, 7
29	33, 9	34, 7	34, 6	33, 9	34, 7
32	34, 5	35	34, 9	34, 5	34, 6

Table 2 Dependence of the recording speed of a homogeneous data array on the frequency of influence and the waveform at 80 dB

Frequency (Hz)	Waveform (Mb/sec)				
	sinusoidal	**meander**	**triangle**	**sawtooth**	**reverse sawtooth**
5	34, 1	34, 3	35, 1	35, 5	35, 2
8	33, 4	33, 9	34, 2	35, 1	35
11	31 8	33, 2	33, 6	33, 9	34, 4
14	29, 5	30	32, 9	33, 2	34, 5
17	27 9	28 7	32, 1	32	33, 7
20	26, 2	26, 5	31, 2	31 2	32, 9
23	23, 5	25 6	29	30 6	32, 1
26	24, 3	25 7	28 7	30, 3	32, 4
29	25, 9	25, 4	28 8	30 7	32, 4
32	27 6	27 8	29, 5	31, 6	33, 9

Table 3 Dependence of the recording speed of a homogeneous data array on the frequency of the influence and the waveform at 110 dB

Frequency(Hz)	Waveform (Mb/sec)				
	sinusoidal	meander	triangle	sawtooth	reverse sawtooth
5	27 8	26 8	33, 6	34, 1	33, 9
8	25, 2	26	30, 3	33, 9	32, 4
11	22 3	23	27	31, 3	30 6
14	19, 2	21, 2	23, 2	29, 2	29 9
17	17	18 8	19, 3	25	29 8
20	14 7	16, 2	18	25, 2	28, 4
23	12 8	14, 9	17 9	23, 9	26, 5
26	12, 4	14, 4	19 8	21 9	26
29	13, 1	15, 9	20, 4	20 7	24, 3
32	16	19, 3	22 6	23, 8	25 7

Analyzing the measurement data at an amplitude of sound vibrations of 110 dB, it was decided to carry out the final measurement by changing the waveform in the reverse order (meander and sinusoid in the last turn). Because exactly with these waveforms, reading-writing speed dropped only 4 times, the process failed (1 time with a meander waveform and 3 times with a sinusoidal waveform).

HDD received critical (as indicated by faulty HDD) damage and stopped its operation during acoustic-vibration influence at a sound pressure of 140 dB with a sinusoidal waveform and a frequency of 26 Hz, which led to a stop-error of operating system.

Table 4 Dependence of the recording speed of a homogeneous data array on the frequency of the influence and the waveform at 140 dB

Frequency(Hz)	Waveform (Mb/sec)				
	sinusoidal	meander	triangle	sawtooth	reverse sawtooth
5	13	23,2	31,2	34,5	34,3
8	5,4	15	30,7	34,1	33,9
11	1,9	9,3	25,4	33,6	34,7
14	0,8	4,1	24,6	32,9	33,5
17	0,1	2,6	23,1	32,1	32,8
20	0	2,2	20,2	31,7	32,2
23	0	0,8	18,5	27,2	28,1
26	Nd	0	16	22,2	25,3
29	Nd	0,1	17,8	22,8	22,8
32	Nd	1,6	19,9	24	24

3. EXPERIMENT RESULTS

Analyzing tables 1-4, we can conclude that the most destructive were the sinusoidal and the meander waveforms. The results of testing the meander and sinusoid type waveforms are presented in the form of a dependency graph of the action frequency and the writing speed (Fig. 2, Fig. 3).

Table 5 Dependence of the recording speed of a homogeneous data array on the frequency of influence and SPL for a meander waveform

Frequency (Hz)	**Amplitude of sound oscillations(Mb/sec)**			
	60dB	80dB	110dB	140dB
5	35,3	34,3	26,8	23,2
8	35,3	33,9	26	15
11	35,2	33,2	23	9,3
14	35,1	30	21,2	4,1
17	34,7	28,7	18,8	2,6
20	34,4	26,5	16,2	2,2
23	34,5	25,6	14,9	0,8
26	34,1	25,7	14,4	0
29	34,7	25,4	15,9	0,1
32	35	27,8	19,3	1,6

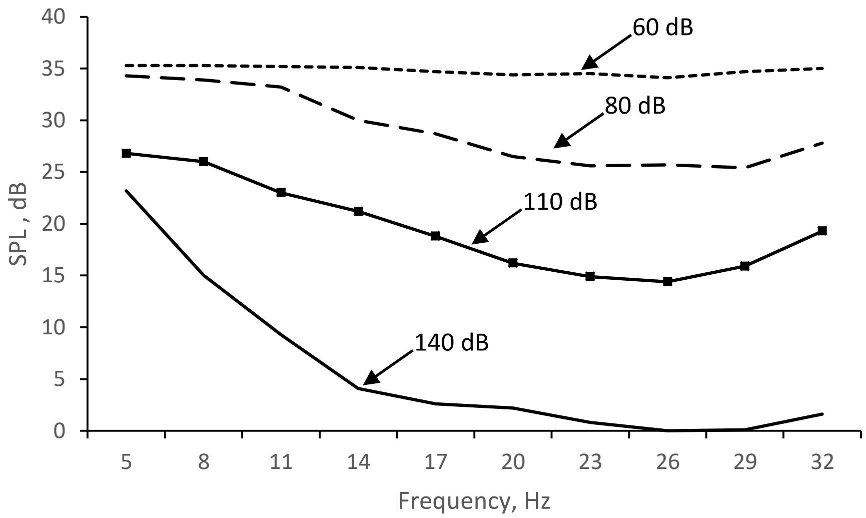

Figure 2 Dependency graph of the recording speed of a homogeneous data array on the frequency of influence and sound pressure for a meander waveform

Table 6 Dependence of the recording speed of a homogeneous data array on the frequency of influence and sound pressure for a sinusoidal waveform

Frequency (Hz)	**Amplitude of sound oscillations(Mb/sec)**			
	60dB	**80dB**	**110dB**	**140dB**
5	35,2	34,1	27,8	13
8	35,1	33,4	25,2	5,4
11	35,3	31,8	22,3	1,9
14	34,6	29,5	19,2	0,8
17	34,2	27,9	17	0,1
20	33,7	26,2	14,7	0
23	33,3	23,5	12,8	0
26	33,6	24,3	12,4	Nd
29	33,9	25,9	13,1	Nd
32	34,5	27,6	16	Nd

In the course of the experiment, it turned out that the acoustic-vibration influence at an amplitude of sound vibrations of 140 dB and a sinusoidal waveform leads to critical damages of the block of magnetic disk (BMD) working field and the complete shutdown of the HDD and, as a result, the computer system on the whole (stop-error of HDD functionality).

For deeper analysis, the result of the acoustic-vibration influence of a meander waveform and a sound pressure level of 140 dB is chosen, since it most fully reflects the state of the HDD during the emitter functioning.

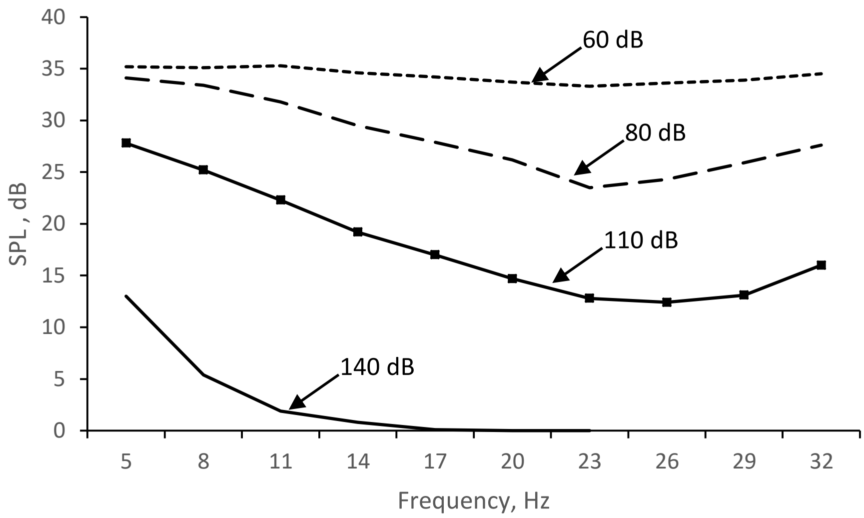

Figure 3 Dependency graph of the recording speed of a homogeneous data array on the frequency of influence and sound pressure for a sinusoidal waveform

Interpolation of the result was carried out using the spline Akima [10].

Analyzing interpolated data (Fig. 4), it is revealed that the greatest destructive influence occurs at a frequency of 27 Hz. After interpolating the research data with a sinusoidal waveform and a SPL of 110 dB, a similar result was obtained.

During the secondary IP faulty, it was revealed that in the result of acoustic-vibration influence, the percentage of damaged BMD clusters of working field in the zone from which data recording and reading operations were performed exceeded 67%. More precise faulty was not possible with the tools, since BMD surface and the profiling of the reading head were critically damaged (revealed during the disassembly of the HDD after all tests), and the microposition system could not hold the reading head for a long time on the track without an aerodynamic cushion.

During the complex technical inspection of the test computer, it was found that the frequencies of the infrasonic range also destructively affect the cooling system. The cooler's support couplings of the central processor cooling system and the power supply unit shifted from the landing sites and propped the cooler axes, interfering their regular operation. Their further work in such a state, with a high probability, will lead to overheating of the system and operation of the thermal relay of the central processor. In addition to the aforementioned damages, there were no other influences of the acoustic-vibration effect on the test computer.

In the course of the study, it was determined that the bifurcation point (in this case total system failure, critical damage to the BMD working field and loss of information) is a frequency of 27 Hz.

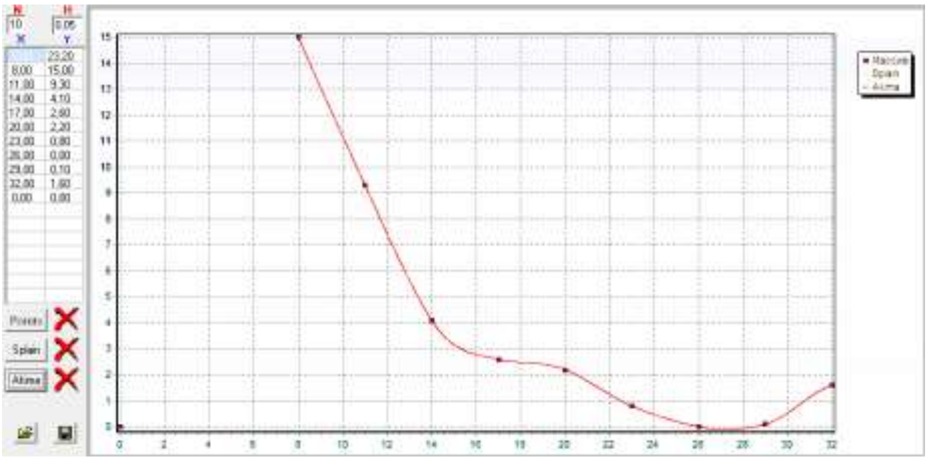

Figure 4 Interpolation of dependency graph of the recording speed of a homogeneous data array on the frequency of the for meander waveform and a sound pressure level of 140 dB) by the Akima spline

4. CONCLUSION

The study results can be summarized as:

1. Acoustic-vibration influences can cause significant deconstructive effects on the computer system.
2. HDD received a critical damage at a sinusoidal waveform and meander signal type.
3. The effect at frequencies of 27 ± 2 Hz most negatively affects the operation of HDD and the computer system on the whole.
4. Basic vibration protection of the A-brand HDDs cannot effectively counteract infrasound influences.
5. The consequence of acoustic-vibration influence is the failure of HDDs functionality, the loss of information and the shutdown of the computer system.

Such an influence can be neutralized with the help of inertial elements, selected with resonance in antiphase to the most critical frequencies of the infrasonic range, gyroscopic suspension and active vibration dampers. A promising way of research in this area is to assess the ability of these methods and tools of protection against acoustic-vibration influence on critical infrastructure computer equipments to protect and counteract acoustic and vibration effects. Moreover, investigation the possibility of modifying these methods and tools with the aim to increase the protection level and neutralize destructive influence will have a good theoretically and practically results.

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