THE IMPROVEMENT OF ACOUSTIC COMPATIBILITY OF A CITY SODAR ANTENNA

Y. N. Ulyanov, M. M. Smirnov, and G. Y. Martynenko

Department of Physical & Engineering, National Technical University “KhPI”, Kharkiv, Ukraine (ulyanov@kpi.kharkov.ua)

Abstract
Wide application of sodars for ecological use in cities is restrained now due to a high spurious radiation level of modern sodar antennas, especially at the angle of about 90° with respect to its main lobe. By an example of the developed sodar horn-reflex antenna, the possibility of essential improvement of its acoustic compatibility necessary for using it in cities is shown. It is shown that the improvement can be achieved as a result of the analysis of mechanical characteristics of an acoustic antenna construction with subsequent tuning out mechanical resonance frequencies of the construction at the expense of variations of its mass and rigid properties. The results of numerical experiments confirm reality of the supposition about the possibility to increase the level of suppression of extraneous sodar antenna radiation up to 60 dB on the basis of the proposed procedure.

Keywords: horn sodar antenna, spurious emission, mechanical resonance, far lobes, finite-element method, natural frequency, solid, electro-acoustic analog method

1. INTRODUCTION
The growing needs of the human society in the information about the real structure and the dynamics of the boundary atmospheric layer for the solution of the whole complex of problems connected with human life and activity cannot be satisfied with traditional meteorological data obtained in the contact way with the help of towers, balloons, helicopters and other carriers.

Advantages of remote non-contact methods with the use of sound waves (acoustic, or sodar, and radio-acoustic atmospheric sounding) are generally known. They allow monitoring, at a low cost, the entire boundary layer in the interests of ecology and meteorology, as well as of aircraft, radiolocation and telecommunication. However, at all innocence of such a sound radiation for human life, the successful use of similar techniques in cities is complicated with some irritating influence on urban population of spurious acoustic radiation in the form of alternating short sound parcels. Thereupon the important engineering problem consists in reduction of a level of unwanted radiation of the sodar antenna, especially on the angle close to 90° relative to its main lobe.

2. FEATURES OF SODAR ANTENNAS OPERATION
Acoustic (sodar) sounding has the ancient history and is based on effects of sound waves scattered by small-scale turbulent inhomogeneities in the planetary boundary layer. The efficiency, innocence of used acoustic radiation, and small cost of sounding equipment have, however, an essential antipode – noise pollution originated from sodar working. It is necessary also to take into account surrounding noise affecting sodar and restricting its efficiency. The complicating circumstance here consists in the use of the audible sonic range. Fig. 1 shows the optimum sound pressure and signal-to-noise ratio frequency dependencies of a typical sodar, as in Krasnenko N.P. (2001), as compared with the auditory human sensitivity. It is easy to see practically full coincidence of the extremum positions on the frequency axis. This fact causes restriction of using sodar in cities and in populated areas at all. It is connected with the irritating effect on a man by emitted sounding parcels acting from non-working directions of a sodar antenna (along its far sidelobes, usually close to 90° in relation to the main lobe).

A level of side lobe suppression, as well as of own acoustic unwanted radiation, for modern monostatic sodar antennas usually averages 30...35 dB at the angle close to 90° with respect to the horizontal, according to Crescenti G.H. (1997). For using in city it cannot be considered as sufficient because the parasitic radiation remains considerable and comparable by the level with a loud speech or shout, what is inadmissible according to sanitary codes, especially at nights.

In our opinion, a reserve of this parameter improvement consists in the account of dynamic proper-


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It is possible to single out four approaches in the direction of the problem solution:

- reduction of a value of the disturbing force;
- increasing of walls damping properties;
- tuning out frequencies of the mechanical resonance;
- providing such a shape of the resonant fluctuations, which down to the limit is orthogonal to the disturbing effect.

Taking into account that the correction by the first item is connected with both the deterioration of the antenna qualitative indices, the increase of the walls damping properties is finite and usually realized at the maximum possible level, so the latter two items take on special significance. They were not taken into account till now when designing and developing acoustic antennas intended for sodar and the radioacoustic equipment.

3. RESONANT MODES ANALYSIS OF A CITY SODAR ANTENNA DESIGN

The design of our worked out horn-reflector city sodar antenna is shown in Fig. 2. The problem of making such an antenna was discussed in the conference paper, as in Ulyanov Y.N. and Butakova S.V. (2003) The guiding horn with the inclined diffractive cap form the basic unit of this antenna, which determines its appropriateness for using in cities. This unit (Fig. 3) is the object of the structural behavior research at resonant modes.

The factors causing occurrence of mechanical resonances of a sodar antenna are connected with the pulse mode of its functioning. In our case they are: sounding period \( T_s = 6s \), sounding parcel duration \( t_p = 0.1s \), working frequency \( f_w = 2600 \text{ Hz} \).

The program of the computational research of mechanical resonances included the following stages:

1) calculation of the strained state at static loading;
2) computation of the natural vibrations spectrum and corresponding natural modes;
3) definition of possible resonant modes;
4) estimation of amplitudes of fluctuations at resonant modes.

Fig. 1. Optimum sodar frequencies and auditory human sensitivity.

Fig. 2. Design of the city sodar antenna.

Fig. 3. Parameters of the main guiding antenna unit.

In order to solve the task, the finite-element method has been used, according to Myachenkov V.I. and others (1989). The feature of this method is that the required unknown functions describing its strained state are defined only at some points of a solid body, at so-called nodes. Nodes represent vertices of elementary substances (tetrahedrons, irregular octagons) into which the entire volumetric construction of the antenna main guiding unit is divided. Deviations from the initial sizes in mechanical constructions under power and temperature impacts with small deformations are described by linear differential equations in partial derivatives. After dividing into finite-elements, the task of these deviations as functions of spatial coordinates is replaced by the equivalent task of finding...
these function values at the finite number of solid elements, that is at nodes. For the equivalent problem to be solved, for static tasks a system of linear algebraic equations with regard to unknown values of deviations at nodes is set, or in dynamic tasks a system of differential equations, in total derivatives with respect to time. In a matrix form the system of equations set for the static task looks like:

$$[K][U]=[P],$$

where: $[K]$ is the stiffness matrix of the entire construction;

$[U]$ is the vector of unknown motions at nodes;

$[P]$ is the vector of static loadings at nodes.

For definition of resonant frequencies, as a rule, the solution of the problem is reduced to solving the task on the eigenvalue, as at a small friction, natural frequencies practically agree with the resonant ones:

$$[M][\ddot{U}]+[K][U]=0,$$

where $[M]$ is the masses matrix of the construction.

Constructive elements of the basic horn of the antenna are made of a plastic having the sufficient rigidity and stability to the weather impact. In Fig. 4, the grip conditions and finite element layout of the basic horn solid-state model are shown.

According to the results of natural frequencies computation, it turned out that the second natural form (12 Hz) is multiple to the repetition rate of sounding parcels (1/6 Hz). Therefore, occurrence of the superresonant mode with an amplitude of not less than the static deflection amplitude is possible. Infrasonic oscillations at the frequency about 12 Hz influence very negatively upon the cardiovascular human system and, as it pointed out in Semenchenko B.A. (2002), can lead to development of hypertensive disease. In order to eliminate the infrasonic radiation, there are added into the antenna design stiffening ribs located longitudinally on walls of the basic horn. The natural frequencies spectrum analysis close to the working frequency have shown that natural frequencies are situated very compactly (Fig. 5).

There are 38 natural frequencies close to $f_w=2600$Hz. Exact coincidence (at the most dangerous multiplicity equal to unit) with the working frequency of the antenna shows the frequency of natural fluctuations $\lambda=767$ (Fig. 6) that results in occurrence of the resonant mode. Excitation of resonant oscillations with 89-th form (Fig. 7) is possible under wideband acoustic probing signals in the presence of the signal frequency divisible by 421Hz.

The proposed approach to studying the possible causes of spurious radiation occurrence for sodar antennas is based on the analysis of the natural frequencies spectrum and on the assessment of chances of excitation resonant operating modes for a given part of a design. Any sodar antenna design can be tested for the presence of resonant modes at its working frequency with the subsequent tuning out from them by changing mechanical parameters of the design. Esti-
mation of absolute values of amplitudes for resonant oscillations with an error of about 20%, can be made by application of static loading from sound pressure upon the area of the radiating walls restricted by nodal curves. Calculation of their exact values is possible when carrying out the numerical research of the forced oscillation of the design subject to internal energy losses of oscillations.

3. Effect of Mechanical Resonances on the Antenna Far Side lobes Level

For estimation of the acoustic antenna far sidelobes distortion caused by coincidence of emitted sound frequencies and frequencies of mechanical resonances in the antenna construction it is possible to apply, described in Sapozhkov M.A. (1978), the electro-acoustic analog method. The antenna radiation pattern is represented as a sum of the horn direction diagram without mechanical oscillations of its case and the direction diagram of an acoustic radiation of a solid with external dimensions of the horn having surface mechanical motions, just as it is shown in Fig. 5.

The sodar horn antenna pattern with the unperturbed case is computed with electrodynamics methods taking into consideration that E-type electromagnetic waves correspond to sound tubes waves, according to Vainshtein L.A. (1966), and that $H_0$ wave in E-plane horn creates the diagram in E-plane, as in Butakova S.V. (2002), with the help of its electric component $E_{ip}$ wave.

Acoustic radiation of the solid corresponding to Fig. 6, can be considered as electromagnetic radiation of a hollow dielectric tube, whose diameter considerably exceeds a working wavelength. Such a dielectric antenna, in accordance with Aizenberg G.Z. (1957), is practically undirected. Therefore the radiated power falling on walls of the basic sodar antenna horn during sounding acoustic parcels emitting, after partial sound absorption by wall material, is almost uniformly distributed in external space. Radiation created in such a way is similar to the evenly heated solid with the spatial distribution similar to Lambert's diagram. Calculations carried out on the basis of the proposed procedure show that acoustic radiation at angle of 90° to the axis of the basic acoustic horn, caused by the antenna mechanical resonance at the sound pressure upon internal walls about 100 dB is comparable to acoustic radiation in the same direction on the sidelobe of this antenna without mechanical resonance.

4. Concluding Remarks

The spurious emission level of about 40 dB achieved by now for the most perfect sodar acoustic antennas, at the angle close to 90° with respect to its main lobe cannot be considered as sufficient for city sodars. The greatest potentialities in the noise-immunity level are inherent in horn acoustic sodar antennas. In addition, the improvement can be achieved, when carrying out the analysis of mechanical characteristics of an acoustic antenna design with the subsequent tuning out its mechanical resonance frequencies at the expense of variations of its mass and rigid properties. The results of numerical experiments confirm the reality of assumption about the possibility to increase the suppression level of extraneous sodar antenna radiation up to 60 dB, on the basis of the proposed procedure, which consists in the choice and analysis of mechanical parameters and resonant modes of the antenna design. Computation is made for the horn city sodar antenna, however it can be made for another types of sodar antennas equipped with an acoustic enclosure too. Moreover, such an analysis is required when developing acoustic sodar antennas of city application with the aim to reveal significant infrasonic components in the spectrum of natural frequencies, as the most dangerous by the degree of adverse influence on human life.

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References
